AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

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419.

Vol. XXI.—August, 1889.

SHIP CANALS IN 1889.

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When the idea of presenting something upon the subject of ship canals first occurred to me, it was my intention to give a brief description of every work of that kind, completed, in progress, and projected, giving its history, principal features, cost actual or estimated, traffic actual or expected, cost of maintenance, and development, without, however, entering into any discussion of details, of merits of different routes, or of the question of canals *versus* railroads—something that would be of general interest and of a sufficiently non-technical character to be easily assimilated even in hot weather. But limited time and the unexpected extent of the task I had set before myself, has hampered me until I feel that the result is hardly more than a ship canal directory. Still I have felt that even that might not be entirely without interest to many, and I trust that omissions and incompleteness will be regarded leniently.

Naturally the paper is simply a compilation and condensation.

For the material for condensation I have been indebted to "Harcourt's Rivers and Canals," to the Annual Reports of the Chief of Engi-

neers, to various scientific and technical publications, the columns of the press, and, more perhaps than to any other one source, especially for the continuous record of the progress of the various projects, to the columns of *Engineering News*.

Completed Canals.—Abroad.

Languedoc Canal.—This canal, known also as the "Canal du Midi," is often spoken of as a ship canal, though its dimensions do not in any degree justify such a classification.

Its claim to the name seems to be in the fact that it was built for the use of the "ships" of that time (17th century) engaged in the coasting trade between the Atlantic and Mediterranean coasts of France, and that for its time it was undoubtedly as great an undertaking as the Suez Canal in recent years.

It forms a communication between Bordeaux, on the Bay of Biscay, and Cette, on the Mediterranean. Its length is 140 miles, summit level 610 feet above the Mediterranean, depth 6 feet 7 inches, and it has 119 locks.

The canal was completed in 1681 at a cost of $7 200 000.

Caledonian Canal.—This canal is located through a remarkable valley called the Great Glen, stretching across the Highlands of Scotland, between Inverness Firth and Loch Eil, a distance of about 60 miles; 38 miles of this distance, however, are occupied by a chain of lakes.

In 1773 James Watt reported favorably upon the project, but nothing was done.

In the beginning of this century, Telford, at the request of the Government, reported upon the project, and was intrusted with the execution of the work, which was commenced in 1804 and completed in 1823.

The Government was led to build this canal by the expectation that it would save vessels a long and dangerous circuit by the Pentland Firth, where previous to the introduction of steam they were liable to be detained for weeks by contrary winds; and, also, that in time of war the canal would afford a convenient refuge for merchant vessels from privateers, and a means by which war vessels might pass rapidly from one sea to the other.

The canal was designed for vessels of 20 feet draught, and it has 28 locks 170 x 40 feet, of 8 feet lift. The width on the bottom is 50 feet, on

the surface 120 feet, and depth 20 feet. The summit level is 100 feet above the sea, and the cost of the work was about $5 000 000. It was a bold and skillful undertaking, but it has not been a financial success. Wars hindered its progress, and so enhanced the price of materials and labor that its cost was nearly double the estimate, and finally, to save expense, the summit cut was not carried to full depth, and will permit the passage of vessels of only 17 feet draught and 250 to 300 tons capacity.

Had the full depth of 20 feet been obtained, the canal would have admitted vessels of 1 000 tons, and doubtless to this fact, more than anything else, may be attributed its failure in a financial sense.

North Holland Canal.—Formerly the only means of access to the port of Amsterdam was by the Texel Roads and the Zuider Zee. The Zuider Zee abounds in shoals and its navigation is difficult, so early in the present century the Dutch Government decided to make a new route for vessels trading with Amsterdam.

The shortest line from Amsterdam to the North Sea, in a westerly direction, was then considered out of the question, on account of the difficulty of maintaining an entrance on the exposed flat coast of the North Sea, and a northerly route through North Holland was adopted, starting from Lake Y, nearly opposite Amsterdam, and opening into the haven of Niewediep, on the Texel Roads.

The canal built on this route was known as the North Holland, and was commenced in 1819 and finished in 1825, at a cost of $5 000 000. It is 52 miles long, 123½ feet wide at the surface, 31 feet wide at the bottom and 18½ feet deep. It has a double tide lock at each extremity, with chambers 237 x 51 feet and 82 x 18½ feet, and three regulating locks.

This canal was of great value to Amsterdam and was of unusual magnitude for the time when it was constructed.

It is now superseded by the Amsterdam Ship Canal and has lost its importance since the completion of the latter.

Crinan Canal.—This canal, across the peninsula of Kintyre, 9 miles long and 12 feet deep, enables vessels of 160 tons to save a circuit of about 70 miles around the Mull of Kintyre.

Gloucester-Berkeley Canal.—The City of Gloucester has direct access to the sea by the River Severn and the Bristol Channel; but for some miles below Gloucester the course of the river is circuitous, and the rapid flow of the tides renders navigation difficult and dangerous.

An act was obtained in 1793 for connecting Gloucester by a direct ship canal with the estuary below, and after much delay this canal was completed by Telford in 1827. It is 16½ miles long, 13 to 20 feet wide at the bottom, 80 to 100 feet wide on the surface, and 18 feet deep.

At the lower end, where it enters the Severn, there is a tide-lock to maintain a constant level.

Witham Canal.—This canal, which gives Boston a direct communication with the sea, available for vessels of 2 000 tons as compared with vessels of 300 tons previously, is one of the most important of recently completed English works of its class.

The canal is 3 miles long, 27 feet deep, 130 feet wide on the bottom, and cost, with some accessory works, $1 000 000.

St. Louis Canal.—This canal was constructed to avoid the bar of the River Rhone.

It extends from the Rhone above the bar to the Mediterranean in the Bay of For, east of the Rhone outlet.

It is 2 miles long, 206 feet wide at low water level, and 19½ feet deep.

Göta Canal.—This canal gives direct water communication across Sweden from the North Sea to Stockholm, a distance of some 300 miles.

The canal proper, however, is but a series of short links connecting a chain of lakes which occupy four-fifths of the distance.

The canal is 46 feet wide on the bottom, 86 feet on the surface, and 10 feet deep, and is very solidly constructed. The summit level is 300 feet above the sea and there are 76 locks.

About 10 000 craft pass through the canal annually.

Suez Canal.—The main features of this canal, the most successful and important of all ship canals thus far completed, as well as the principal incidents of its inception and construction, are very generally known, yet a brief résumé seems necessary to make the record complete to date.

The value of a channel of communication between the Mediterranean and Red Seas, through the Isthmus of Suez, is evident from a glance at a map, saving, as it does, a long, circuitous route around the Cape of Good Hope for maritime traffic between Europe and the southern coasts of Asia.

The construction of such a canal is not a modern idea, but originated in remote antiquity. It is said that a canal across the Isthmus existed in the time of Sesostris, 1600 B. C., which later was abandoned. Nero

and Darius both contemplated constructing a canal here, and Harcourt states that there is evidence that a canal for small vessels was opened and maintained from about 600 B. C. to 800 A. D., but was subsequently allowed to fall into decay. Pope Sixtus V is said to have thought of cutting the canal in 1585. Louis XIV of France had a proposition submitted to him to construct a canal, and Napoleon I gave the project very serious consideration, but was deterred from carrying it into execution by the erroneous results of his engineers' surveys, these surveys showing that the level of the Red Sea was 10 meters above that of the Mediterranean.

In 1847 these figures were shown to be wrong, and accurate surveys demonstrated that the mean level of the two seas was the same, though the tides in the Mediterranean were only 1 foot, while those in the Red Sea were about 6 feet.

In 1854 M. de Lesseps obtained the concession for the canal, but much time was occupied in discussions and diplomatic negotiations, and the inauguration of the work did not take place until August 25th, 1859.

Work really began in earnest in the following year, and August 15th, 1869, the waters of the two seas mingled in the Bitter Lakes. November 17th of the same year the canal was formally opened and traversed by a numerous fleet of vessels of all nations.

The canal extends from Port Said, on the Mediterranean, at sea level and without locks, across the Isthmus by the most direct route, which carries it through the depressions of Lakes Menzallah, Ballah and Timsah, and the Bitter Lakes, to Suez on the Red Sea, in a line nearly due north and south. Its length is 99 miles, its width on the surface varies from 196 to 328 feet, according to the strata through which it is excavated, but the bottom width is 72 feet throughout. The depth is 26 feet. Through a portion of the Bitter Lakes no excavation was necessary, and the deepest cut, at El Guisr, was only 85 feet to the bottom of the canal. The amount of excavation was about 98 000 000 cubic yards, mostly sand and clay or a mixture of both, except at places south of the Bitter Lakes, where some rock was encountered. The cost of the canal was about $100 000 000.

A harbor formed by two breakwaters was constructed at Port Said, to maintain the channel dredged from the entrance of the canal to deep water of the Mediterranean.

These breakwaters are 4 600 feet apart at the shore ends, and 2 300 feet apart at the end of the eastern breakwater, which is 6 300 feet long, while the western one extends 3 500 feet farther, to deflect the silt laden littoral current from the entrance. During the first two or three years the work on the canal was done almost entirely by forced Egyptian labor, as many as 30 000 men being employed at a time. In later years the work was done almost exclusively by machinery.

From the day the Suez Canal was opened its business increased steadily and rapidly up to 1877, when it amounted to 1 663 vessels annually. In the two following years the traffic decreased, owing to a general depression in trade, then it went up with a jump, more than doubling in amount from 1879 to 1882, and rapidly grew through 1883, when it amounted to 3 307 vessels of a net tonnage of 5 775 861 tons.

With this amount of traffic it became apparent that the capacity of the canal with its original dimensions, and only fourteen *gares* or turn-outs, was practically reached, and it was evident that speedy and ample measures must be taken to increase its capacity.

Two projects were discussed—one to build a second canal alongside the original one, another to widen and deepen the present canal.

The latter project was approved in the beginning of 1885, and the canal is to be enlarged to a depth of 29.5 feet, and a width, 26 feet below the surface, of from 213 to 246 feet on tangents, and 246 to 262 feet on curves of less than 8 200 feet radius. The total amount of excavation requisite to complete this enlargement is estimated at 91 000 000 cubic yards, and the estimated cost is about $41 000 000.

The enlargement, however, is to be carried out in three successive stages.

First.—Deepening the canal to 27.8 feet and increasing the bottom width to 121 feet.

Second.—Widening to the final dimensions.

Third.—Deepening to the final dimensions.

The first stage of this work, to give a depth of 27.8 feet, is now in progress, estimated cost about $12 000 000, and pending its completion the traffic of the canal since 1883 has increased more slowly, although the canal has been opened to night traffic, reducing the time of transit from thirty-six to sixteen hours, and the increase has been more in the way of an increased average tonnage per vessel than in the number of vessels.

This increase in the average tonnage of the vessels is very instructive. In 1870 it was 1 000 tons, in 1888 it was 2 743 tons.

With the completion of the enlargement, the traffic will undoubtedly take another vigorous bound upward.

The financial success of the canal can be best judged by the value of its shares.

The ordinary shares drew dividends in 1886 of over 11 per cent. and preferred shares nearly 17 per cent. A year ago ordinary shares of $100 sold in London at $427.50, and in Paris at $434.

Commercially this canal is of more importance to England than to any other nation, as it shortens the voyage to her Indian possessions about 7 000 miles as compared with the voyage around the Cape of Good Hope, and about 75 per cent. of the traffic of the canal is English.

Strategically also it is of vital importance to England, and as events have already shown, in case of complications she will possess and hold it at all hazards.

Amsterdam Canal.—This canal, which the circuitous route through the North Holland Canal, and the increasing size and draught of the vessels trading to Amsterdam, forced that city to construct, in order to hold its own against the more favorably situated ports of Rotterdam and Antwerp, extends due west from Amsterdam across the peninsula of Holland to the North Sea, a distance of 15½ miles. Its bottom width is 88½ feet, its surface width 187 feet, and its depth 23 feet.

The greater portion of it was constructed through a shallow lake, and the remainder through low sand dunes. The principal difficulties in its construction were the formation and maintenance of the entrance on the North Sea, and the complete re-arrangement of the system of drainage of the region traversed by it. This drainage is now pumped into the canal.

At the North Sea end there is, as on the North Holland Canal, a double lock, with chambers 390 x 60 feet and 227 x 40 feet. At the Zuider Zee end there is a triple lock, with one chamber 315 x 60 feet and two chambers 238 x 47 feet.

In the construction of the canal and harbor 21 000 000 cubic yards of sand were removed by dredging, much of it at a cost of only twopence per yard.

The canal was commenced in 1865 and completed in 1876, at a total cost of nearly $15 000 000.

Two railways and one road cross the canal on swing bridges.

The canal is doing a large and increasing traffic, as many as seven hundred vessels having passed through its double locks in one day, to the great benefit of Amsterdam.

St. Petersburg Canal.—The plans for this canal were matured in 1872–73, but work was not commenced until 1878. It was partially opened in October, 1884, and finally completed and formally opened by the Czar and Czarina in the presence of a large number of distinguished persons, May 27th, 1885.

The length of the canal is 18 miles; maximum width, 350 feet; general width, 180 to 240 feet; depth, 22 feet. The total excavation amounted to about 63 000 000 cubic yards of clay, sand and gravel, most of it used in the construction of the embankments. The cost of the canal was about $9 000 000.

The canal starts from the mouth of the Neva, where it opens into a large basin, and trends southward about 2 miles, with a width of 207 feet between embankments. It then joins the canal to Cronstadt and at the same point branches to meet the Neva above St. Petersburg. The foundations of the embankments were a double row of timber cribs filled with gravel, their internal faces planked and the excavated material pumped into the space between. The slopes of the dykes are protected with riprap on a bed of ballast.

The personnel and plant employed upon the canal consisted of 3 500 men, 13 dredgers, 3 locomotives with 230 cars, 86 lighters and barges, 12 tugs and 7 stationary engines.

The canal has both strategical and commercial importance, opening up as it does communication for war ships and large vessels of all kinds directly with St. Petersburg. Previous to the construction of the canal the cargoes of all vessels drawing over 9 feet had to be lightered 20 miles up the river to St. Petersburg, and all goods for export had to be lightered down the river in the same manner.

The effect of this canal was to increase the exports of St. Petersburg from 280 000 tons in 1883 to 950 000 tons in 1886, but it was at the expense of Cronstadt, the commerce of which was practically destroyed.

Ghent-Terneuzen Canal.—Beginning as far back as 1251 several canals have been constructed to maintain the communication of Ghent with the sea, the last one being completed in 1827.

The distance from Ghent to Terneuzen by this canal was only 21 miles, as compared with 105 miles by the River Scheldt.

It, however, proved inadequate for the constantly increasing size of vessels since its construction, and it has recently been straightened and enlarged to a bottom width of 56 feet, a surface width of 173 feet, and a depth of from 20 to 22 feet, with most beneficial results to the City of Ghent.

Completed Canals.—At Home.

Welland Canal.—The history of this canal is similar to that of St. Mary's, though on a smaller scale.

It was begun in 1824 and finished in 1833, by private parties, the depth being 8 feet.

In 1841 it was assumed by the Canadian Government, and its enlargement to 9 feet commenced The depth was afterwards increased to 10 feet by raising the embankments, and the locks enlarged to correspond.

In 1867 the canal was capable of passing a 400-ton vessel, and it had cost up to that time about $7 500 000.

In 1871 it was found that it would be necessary to again increase its capacity, and the work of enlargement was commenced soon after, and completed in 1887.

It was intended at first that this enlargement should consist of an increase in the size of the locks to 270 x 45 feet, and an increase in the depth of the canal to 12 feet; but almost as soon as the work was commenced it was found that this would not be sufficient, and the depth was increased to 14 feet.

The estimated cost of this enlargement was between $12 000 000 and $13 000 000; the actual cost was considerably in excess of that sum.

The canal is 27 miles long, and extends from Lake Erie to Lake Ontario, parallel with and west of the Niagara River. Its depth, as above, is now 14 feet, and its bottom width 100 feet. It has 27 locks, with a total lift of 330 feet, and will pass vessels of 1 000 tons.

A further enlargement is very likely to be undertaken in the not far distant future.

St. Mary's Canal.—This canal, which forms the outlet of Lake Superior, is unique in several respects.

It is 1 mile long and has at present a depth of 16 feet. It contains the largest lock in the world, 515 feet long, 80 feet wide in the chamber, 60 feet wide at the gates, 17 feet of water on the sills and a lift of 18 feet.

The canal was originally constructed in 1855, and there were 2 locks 350 x 70 feet, with 12 feet of water on the sills, and 9 feet lift each. About 1870 it became evident that the capacity of the canal had been nearly reached, and the work of enlargement was undertaken.

This work consisted of the construction of the present lock and the deepening of the canal 16 feet.

These improvements were completed in 1881 at a cost of about $2 500 000, with a most astonishing result upon the traffic of the canal.

The number of vessels increased and their size and draught increased to correspond with the increased water-way. The tonnage of the canal increased from 1½ million tons in 1881, the first year of the enlarged canal, to 4½ million tons in 1886—*i. e.*, it trebled in five years.

In 1888 the tonnage was over 5½ million tons.* From 1885 to 1886 the total tonnage increased 37 per cent., and from 1887 to 1888 the average tonnage per vessel increased some 20 per cent., the average now being about 657 tons.

The annual tonnage of the canal is now nearly as great as that of Suez. 1 685 vessels have passed through the canal in one month.

In 1886 it was seen that the ultimate capacity of the canal would be reached in two or three years—that capacity being 96 vessels per day of twenty-four hours, and 84 having already passed in that time; and a still further enlargement was proposed, and is now in progress. This will consist of a lock 800 x 100 feet, with a depth of 21 feet on the sills and a lift of 18 feet, and the deepening of the canal to 20 feet.

The new lock is to be placed upon the site of the two old ones, and will be used in connection with the present new one. The cost of the enlargement is estimated at $4 738 865, and the time for its execution five years.

If, on the completion of this enlargement, the traffic of the canal takes such an upward bound as it did after the last enlargement, and there is no room to doubt that it will, Suez, even with its own enlargement completed, will have difficult work to keep pace with it.

The present lock in this canal is undoubtedly the finest, as it is the largest, in the world. It is manipulated entirely by hydraulic power furnished by the fall at the lock, and the operation of hauling in, locking and hauling out a vessel is easily accomplished in thirteen minutes.

* For the year ending July, 1889, the tonnage was 6 932 203.

The cost per ton of passing vessels through the canal in 1882 and 1883 was one and a half to two cents; it is now about one-half cent.

Des Moines Canal.—This canal gives a passage around the Des Moines Rapids of the Mississippi River. Its length is 7.6 miles; width, 300 feet; depth at extreme low water, 5 feet, and at high water, 16 to 26 feet. The locks in this canal are 350 x 80 feet. The total cost of the canal about $4 500 000.

In 1885 about 1 000 vessels passed through this canal.

Louisville and Portland Canal.—This canal, around the falls of the Ohio at Louisville, is similar to the Des Moines canal. In 1885, 5 000 vessels, of a total tonnage of 1 217 231 tons, passed the canal.

Canals in Progress.—Abroad.

Corinth Canal.—This canal will cut the isthmus of the same name, uniting the waters of the Ægean Sea and the Gulf of Lepanto, and make an Island of the Morea.

The Isthmus of Corinth is a narrow neck of land, with a least width of not more than 6 kilos (3.73 miles), and a maximum elevation of about 80 meters (262.5 feet). It is a plateau between two chains of mountains, Mt. Gueranicus on the north and Mt. Onicus on the south, about 3 000 and 2 000 feet high respectively.

The ancients, Periander, Tyrant of Corinth, in 628 B. C.; Demetrius Poliorcetes, one of the successors of Alexander the Great; Cæsar; and Caligula had all seen the commercial advantages and importance of a canal at this point, and Nero actually undertook the execution of the project, and the evidences of his work, after the lapse of eighteen centuries are perfectly distinguishable, and show the measure of the human force that this Emperor had at his command.

On the Ægean side there was a trench 70 meters (230 feet) wide at the highest part, 40 meters (131.3 feet) at the lowest, and about 200 meters (656 feet) long. The earth was banked up on both sides and the trench ends abruptly in a nearly vertical face.

On the Corinth side vestiges of Nero's work are also visible, and across the entire breadth of the Isthmus is a succession of pits 2 meters (6.56 feet) square, where soundings were made to a depth of 20 meters (65.6 feet).

There was a great demonstration at the inauguration of this work, and Nero turned the first sod with a golden spade, in approved modern

style. He is said to have abandoned the project upon being informed by scientists that the sea was higher on one side of the Isthmus than on the other.

In 1881 a French company was organized with a capital of $6 000 000, M. de Lesseps being honorary president. Three routes were surveyed across the Isthmus, and the one finally selected was the same as the ancient one of Nero. The right of way and uncultivated land on both sides were given by the Greek Government on condition of the work being completed without subsidy.

May 4th, 1882, the work was inaugurated, the King of Greece turning the first sod with a silver spade and the queen firing a train of dynamite mines. The line of the canal is perfectly straight and its total length is 6 400 meters (4 miles). Its section as originally proposed was 22 meters (72.18 feet) wide on the bottom, and 8 meters (26.25 feet) deep at low water. The side slopes 1-10 in rock, 2-1 in sand and 1-1 in firm earth, giving a water surface width of from 23.6 meters (77.43 feet) to 45 meters (147.64 feet). It was expected that the canal could be finished in four years, and a contracting firm took the job for $5 280 000, but inaccurate estimates as to the amount and quality of rock to be excavated, the necessity for flattening the side slopes and the corresponding increase of excavation have greatly prolonged the work and increased the expense.

The original contractors were obliged to throw up the work, and it is being completed by another firm. It is now expected that the canal will be completed in 1890 or 1891, and the total cost is variously estimated at from $9 000 000 to $12 000 000.

The completed canal will be 4 miles long, with a surface width of about 28 meters (91.87 feet), a bottom width of 16 meters (52.42 feet), and a depth of 8.5 meters (27.89 feet). The depth of the cut at the highest part of the Isthmus will be 288 feet. The personnel and plant employed upon the canal has naturally varied with the progress of the work; but at its maximum has been about 3 000 men, 15 locomotives, 700 cars, 6 or 8 dredges, with their attendant tugs and barges. The maximum day's work has been 8 000 cubic meters (10 464 cubic yards). The total amount of excavation will be about 8 500 000 cubic meters (11 118 000 cubic yards), of which some 5 000 000 cubic meters (6 910 000 cubic yards) will be rock. Up to the end of last year something over 5 000 000 cubic meters (6 910 000 cubic yards) had been removed.

The work on this canal has been especially interesting from the various systems of attacking the great mass of excavation that have been successively tried.

Two roads and one railroad cross the canal at a height that will clear the masts of all vessels.

This canal will shorten the voyage of vessels going from the Adriatic Sea to Turkey and Asia Minor by 185 miles, and those coming through the Straits of Messina by 95 miles.

It is estimated that the annual tonnage making use of the canal will be 4 500 000 tons, and the tolls for vessels from the Adriatic will be twenty cents per ton, and those from the Mediterranean ten cents.

North Sea-Baltic, or Holstein Canal.—Considering the auspices under which it is to be constructed, and the principal incentive to its inception, this canal will probably be the most commanding work of its kind in Europe.

The project for a ship canal between the Baltic and North Sea dates back about forty years. There are, however, three small canals now in existence between the two seas, one of which—one of the oldest canals in Europe—is still in use, and was commenced in 1391 and completed in 1398.

Another was constructed in 1525, and the third, projected in 1571, was commenced in 1777, and completed by King Christian of Denmark in 1785. This latter has a depth of 10½ feet.

Prussia had given the subject of a ship canal serious consideration previous to 1866, but the war of that year gave the matter a quietus.

In 1878 the project was again brought forward in a vigorous manner, first by private parties, and then by the Government, which gave the entire subject careful legislative consideration during 1881–83, and finally approved the bill in June, 1886.

June 3d, 1887, the German Emperor officially inaugurated the canal, and only last month proposals for some 15 000 000 cubic yards of additional excavation were advertised for by the Imperial Commission at Kiel.

All the projects for this canal having originated in military and political considerations, the same considerations controlled the selection of the final route, from the important naval station of Kiel, on the Baltic, to Brunsbüttel, on the deep water at the mouth of the Elbe, from among some sixteen proposed locations.

From the Elbe the canal passes through swampy land, and then through gradually rising ground, to the "divide" 82 feet above the sea.

Thence to the Eider, a portion of which is utilized, thence to the Eider Lakes, and thence *via* the Eider canal, rectified and enlarged, to Holtenau, near Kiel.

The length of the canal will be between 60 and 61 miles, the usual radii of curves 4 900 and 6 500 feet, with a minimum of 3 275 feet.

The chief value of the canal being in the speed with which it can be traversed, the curves will be as easy and few as possible. The average cross-section of the canal will be 85 feet 3 inches wide at bottom, 197 feet at water surface and 27 feet 10½ inches deep, giving 3 920 square feet of prism, which will permit the ordinary Baltic vessels to pass without trouble. The lakes and special sidings will accommodate war vessels. The depth will possibly be increased to 29 feet 6 inches, and the future enlargement of the canal is provided for by the purchase of a strip of land along the south side of the canal.

The canal is a thorough cut, with tidal locks at each end. The mean range of tides in the Baltic is about 1 foot 8 inches above and below the canal level, and in the Elbe 4 feet 6 inches above the same level.

At Brunsbüttel there will be three locks, viz., one 275 x 41 feet, one 412 x 82 feet and one 1 180 x 196 feet, and at the Baltic end one large one; this latter, however, will be usually open. The locks will be of massive construction, worked by hydraulic power.

Four railroads and several highways will cross the canal on draw-bridges.

The total amount of excavation is 67 000 000 cubic yards, and the estimated cost of the canal is $39 000 000. Of this sum $12 500 000 represents the excess cost of the work as a military canal over what it would cost for purely commercial uses. The estimated cost of maintenance is $450 000 to $500 000.

The commercial advantages of the canal are the saving in distance, time, pilot dues, and loss in going around Denmark. The saving in distance by vessels coming from the south and west of London to the Baltic is 237 miles, and from German ports some 425. The saving in time is from thirty hours for steamers to four days for sailing vessels. The greater safety is also an important item, 200 vessels being annually lost in the dangerous passage from the North Sea to the Baltic.

The North Sea-Baltic traffic is variously estimated at from 36 670 to 40 000 vessels annually, with a registered tonnage of 12 240 000 tons, 5 500 000 to 9 000 000 tons of which would use the canal at a toll of eighteen and three-fourths cents per registered ton.

The great charm of the canal, however, is its military importance, allowing the German fleet to be concentrated either in the North Sea or the Baltic with great rapidity.

Manchester Canal.—This canal, now in process of construction, will make the City of Manchester, at present 50 miles from the sea and 35 miles from the head of the tidal estuary of the Mersey, practically a seaport, and will completely alter the destination of an immense amount of tonnage now entered or cleared at London, Hull, and especially Liverpool.

It is said that the scheme for connecting Manchester with the sea dates back to 1712. In 1882 the matter was taken up vigorously by the local authorities and capitalists of Manchester. The first project considered was to deepen and widen the Irwell, so as to make a tidal waterway, a second Clyde, from the bar of the Mersey to the Manchester docks, a distance of 50 miles. Thorough surveys and studies led to the rejection of this project, and the adoption of the plan on which the canal is now being built, made by Mr. Williams, C. E.

From the outset great opposition was encountered from the Liverpool and Mersey interests, and from the several important railroad companies, whose lines cross the line of the canal, and which would be put to large expense to modify their lines so as not to interfere with the navigation of the canal.

This opposition delayed the passage of the canal bill in Parliament for several years, and it was not until the summer of 1887 that this opposition was overcome and the bill finally passed. The capital of the company was immediately raised, and the contract for the construction of the canal given out the same year. Work was commenced at once, and is now being vigorously pushed, so that there seems to be no doubt but that the canal will be finished within the contract time of four years.

The length of the canal is a little over 35 miles from Manchester to the Mersey estuary, separated into two divisions:

First.—A tidal division from Eastham through the Mersey estuary to Runcorn, 12 miles; then inland 8 miles further to Warrington, with a bottom width of 100 feet and a depth of 26 feet at low tide.

Second.—A canal division from Warrington to Manchester, 15½ miles long, with a bottom width of 100 feet, a depth of 26 feet and a surface width of 300 feet.

There are four locks, or rather series of locks, these locks being built in groups of three of different sizes, and with intermediate gates, so that any size of vessel may be passed without waste of water. The total rise of the canal is 60 feet. The total amount of excavation is about 48 000 000 cubic yards, and the contract price for the work is $30 000 000.

The personnel and plant now engaged upon the canal is about as follows: 15 000 men, 70 steam shovels, 50 steam cranes, 150 locomotives, 5 000 dump cars, etc., etc., and an average of over 1 000 000 cubic yards per month are being taken out. The work on the canal seems to be a model of perfect organization and business-like procedure.

The figures of the expected traffic of the canal I am unable to give; but there seems to be no question that it will be a financial as well as an engineering success, there being a very dense manufacturing population within a radius of a few miles of Manchester, to which supplies must be brought and from which manufactured products must be taken away.

Canals in Progress.—At Home.

Cape Cod Canal.—The project for a canal across Cape Cod was broached a little over two hundred years ago and nearly a hundred years ago complete surveys had been made for the work.

It is only within a few years, however, that work has actually been commenced, and it has not progressed very rapidly.

The line of the canal extends from the mouth of Monumet River, Buzzard's Bay, to a point south of Sagamore Hill, on Barnstable Bay. The length of the canal is 7.6 miles, and the deepest cut is only 25 feet to high water. The proposed section of the canal is 200 feet wide and 23 feet deep below low water. The amount of material to be excavated is about 18 000 000 cubic yards, and the cost is variously estimated at from $3 000 000 to $9 000 000. Time for completion was put at from three to five years. Two miles of the canal are stated recently to be finished to a depth of 15 feet. This canal would shorten the route from Boston to ports south from 70 to 140 miles, and the saving in time for sailing vessels is estimated at an average of three days.

The expected traffic of the canal is put at 4 000 000 to 5 000 000 tons.

The canal has military advantages as important as its commercial ones.

Harlem Canal.—This canal, which will connect the East and Hudson Rivers by way of Harlem River and Spuyten Duyvil Creek, will be about 8 miles long, 15 feet deep and 400 feet wide.

The history of this work dates back to 1874, when General Newton made a survey for the canal. His report was published in 1875, and additional ones in 1876 and 1881. In 1879 Congress appropriated $400 000 for the work, and in 1887 proposals were advertised for and the contract awarded in December of the same year.

The work was commenced early in 1888 and is now in progress. The estimated cost is $2 700 000.

Columbia Canal.—This canal will connect the Congaree and Broad Rivers, S. C. It is 5 miles long, 10 feet deep, 150 feet wide at the surface.

Over a mile of this canal, including the most difficult portion, is already completed. The canal will give Columbia and the Broad River a water outlet to the sea at Charleston.

Cascades Canal.—This canal, now in process of construction around the Cascades of the Columbia River, will be 3 000 feet long, and will have two locks, 462 x 80 to 90 feet, with 8 to 24 feet of water.

This canal will give an outlet to the great plain of the Columbia, as yet almost entirely undeveloped.

Nicaragua Canal.—The birth of the idea of a ship canal across the Central American Isthmus is practically coincident with the discovery of the New World, as it sprang into existence the moment it was found that there was no natural strait connecting the two seas.

But, though the project was frequently discussed and numerous so-called surveys made, nothing like an accurate survey was made until within the present century.

Immediately the Central American colonies threw off the Spanish rule and gained their independence, the project came prominently to the front. In 1836–37 Mr. Bailey made a partial survey, confined entirely to the western portion of the line, between Lake Nicaragua and the Pacific.

In 1850–51 a thorough survey of a complete route from the Atlantic

to the Pacific was made by Colonel O. W. Childs, and plans and estimates presented for a canal 50 feet wide at the bottom, from 78 to 118 feet wide at the surface and 17 feet deep, the estimated cost being a little less than $33 000 000. Colonel Childs' work is of interest as being the first survey made anywhere on the American Isthmus which was really deserving of the name, all previous ones being wholly or in part based upon mere reconnoissance, estimate, or even hearsay. A commission of English engineers and capitalists which examined Colonel Childs' plans came to the conclusion that a canal of the proposed dimensions would not meet the requirements of ocean-going vessels, nor could the commission see at that time sufficient prospective traffic to make the canal a financial success, and consequently the project was dropped.

When the United States Government in 1870–75 undertook through the Navy Department its comprehensive system of exploration of the American Isthmus from Tehuantepec to the head waters of the Atrato, to determine where was the best route for an interoceanic canal, the Nicaragua route was one of the first ones surveyed. Captain Lull, in command of the expedition, presented plans for a ship canal with a bottom width of 50 to 72 feet, a surface width of 106 to 165 feet and a depth of 26 feet, estimated cost a little less than $66 000 000.

In 1876 and 1880 Civil Engineer Menocal, U. S. N., M. Am. Soc. C. E., the engineer of Captain Lull's expedition, revised portions of the route, and, in 1885, radically modified the eastern portion. In the spring of 1887 a concession was obtained from Nicaragua by American capitalists for the construction of a canal, and in the latter part of the same year a large and completely equipped engineering force was sent to Nicaragua to thoroughly re-survey and definitely locate the axial line of the canal. Plans and estimates for a canal with a bottom width of from 80 to 120 feet, a surface width of from 80 to 340 feet and a depth of 30 feet, based upon the location made by this expedition, were prepared in the latter part of 1888, the estimated cost being about $66 000 000, and the time for completion five years.

The last Congress passed the bill incorporating the company with a capital of $100 000 000, with power to increase to $200 000 000, and the work of construction has already commenced.

The distance from sea to sea by the canal as now located is 170 miles. Less than 30 miles of this distance, however, is actual canal, the remainder being lake, river and lagoon navigation. In this respect it resem-

bles the Caledonian Canal. The summit level is 154 miles long and 110 feet above the sea. There are six locks. The principal features of this canal are the creation of 64 miles of slack water in the San Juan River by means of a dam and the formation of several miles of lagoon navigation by impounding the surface drainage by a series of embankments. The estimated time of traversing the canal is 28 hours, and the expected traffic when first opened is not less than 6 000 000 tons annually.

The magnitude of the benefits resulting from the opening of this canal it would be impossible to overstate. It will shorten the commercial water routes of the world from 2 000 to 6 000 miles, and the routes between our eastern and western seaboard by 8 000 miles.

Exceptional as has been the success of the Suez and St. Mary's Canals, the Nicaragua Canal will possess all the favoring elements of both in an enhanced degree.

The Suez Canal opened a shorter route to comparatively fully developed countries, and its business has been almost entirely due to the diversion to itself from longer routes of an already existing traffic.

The St. Mary's Canal, on the contrary, is the only outlet of a region the development of which has been rendered possible by the canal itself, and it may be said to have created its enormous traffic.

The Nicaragua Canal will open up a direct route to regions that, although they already yield a traffic of 6 000 000 tons per annum (which will immediately seek the canal), may be said to have just begun to develop, and the canal will not only divert this existing traffic to itself, but will in addition create a business the proportions of which it is difficult, if not impossible, to estimate.

The increase in the traffic of the St. Mary's Canal from 1 500 000 tons in 1881 to 4 500 000 tons in 1886, as the result of the development of the region about Lake Superior, may, however, serve as a basis for a general idea of the future traffic of a canal which will practically be to the Pacific Ocean what the St. Mary's Canal is to Lake Superior—its only outlet.

PROJECTED CANALS.—ABROAD.

Birmingham Canal.—The rivalry between the great English manufacturing centers, greatly intensified by the construction of the Manchester Canal, will doubtless result in the near future in the construction of similar works for the benefit of Birmingham, Sheffield, Bristol, and other cities. Judging, however, from the numerous projects which

have been advanced within the past two or three years for giving Birmingham canal communication with almost everywhere, that city feels the rivalry and the disadvantages of its inland position most keenly, and is likely to be the first to follow the example of Manchester.

The principal projects so far are: a barge canal to the Trent; a ship canal to London, estimated cost $5 000 000; a ship canal to the Mersey, consisting of a concreted channel 60 feet wide, 11 feet deep, capable of passing a 300-ton vessel, and estimated to cost $8 000 000; and a ship canal to the Severn, estimated to cost $6 250 000.

The latter project seems now in a fair way to be put through. The outgoing traffic of Birmingham is stated at 2 000 000 tons and a toll of four shillings is spoken of.

Great Western Canal.—This canal would be in reality a prolongation of the Birmingham Canal, in the interests of the manufacturing and commercial centers tributary to the Bristol Channel.

The projected route is from Stalford, on the Bristol Channel, *via* Taunton to Seaton, a distance of 62 miles. The canal is to be 125 feet wide at the surface, 36 feet wide at the bottom, and 21 feet deep. Estimated cost, $15 000 000.

The canal would save a voyage of 300 miles around Land's End.

Newcastle-on-Tyne Canal.—The project for a ship canal from the Tyne to the Solway Firth, first talked of some fifty years ago, was again brought forward about five or six years since, and some work done in the way of surveys.

The distance from sea to sea is 80 miles, of which some 12 miles are now navigable by vessels of large size.

It is claimed the canal would offer a convenient short cut for ocean steamers from one coast to the other.

Scotch Canal.—Within the past year a project for a canal from the Clyde to the Forth has been talked of. The length would be 35 miles, and the rise 156 feet. There is at present a 9-foot canal along the route, and it is said there would be no great engineering difficulties to overcome. Estimated cost from $7 500 000 to $10 000 000.

It is claimed that for Channel steamers between Ireland or the west coast of Scotland, England or Wales, to the east coast or the Continent, the canal would be of great benefit, shortening the voyage and avoiding the dangerous navigation around the north of Scotland; that it would also open up the coal and oil districts of Scotland, and that vessels from America to the east coast, the Baltic and the Continent would be benefited; but this latter is doubtful.

Important military advantages are also claimed for the canal, as it would permit the rapid concentration of war ships on either coast.

Irish Canal.—The project for a canal across Ireland, between Galway and Dublin, attracted some attention in England in 1883 and 1884.

It was proposed to enlarge the existing canal to a width of 100 feet

on the bottom and 200 feet on the surface, and a depth sufficient to permit the passage of the largest ocean steamers. The length would be 127 miles, and there were to be thirty locks.

A preliminary estimate of cost was $250 000 000. Further studies reduced this to $100 000 000. Alternative plans to accommodate vessels of 2 500 and 1 500 tons were estimated at $60 000 000 and $40 000 000 respectively. It was claimed that by using this canal transatlantic steamers to ports on the Irish Sea would save both in time and length of sea voyage. A press comment upon the project at the time was that the "scheme is not much more visionary than the Manchester Canal."

Bay of Biscay-Mediterranean Canal.—This is a project which comes up every little while in France, and which would amount practically to an enlargement of the Languedoc Canal.

One of the proposed routes would follow closely that of the present Languedoc Canal from Bordeaux to Narbonne.

The other starts from the Bay of Biscay at Arcachon, south of the mouth of the Gironde, and runs northeast to the valley of the Garonne; thence along the left bank of that river to Toulouse; thence in a direct line to Narbonne. The total distance is 267 miles. The canal will be 120 feet wide in rock cutting and 147 feet in embankments; width of passing places, 203 feet; depth, 25 to 27 feet. The summit level will be 557 feet above the sea, and the locks will have lifts of 30 feet and over. The deepest cutting will be 163 feet, at Naurose. The estimated cost of the canal is $130 000 000, and it would save a voyage of 700 miles around Spain.

North Sea-Mediterranean.—This is one of the most remarkable of great canal projects recently under consideration.

Like most other enterprises of this character, it is old in conception, dating back to the beginning of the Christian era.

It seems to have first taken definite shape about ten years ago in a plan for a canal from Marseilles to Lyons, and thence to Dunkirk. A second route was from Marseilles to Lyons, and thence to Paris and Rouen.

The portion of this last route from Paris to the English Channel seems liable to be executed at a not distant date, a French company having offered within the year to execute the work at its own expense if it is granted a toll of 60 cents per ton on all vessels entering the canal above Rouen.

The proposed canal would be 20 feet deep, and extend along the Seine from Rouen to Paris, 112 miles.

Brussels Canal.—The City of Brussels is agitating the project of deepening her present 10-foot canal to the sea, built in 1836, to a depth of 21-22 feet, to admit vessels of 2 500 to 3 000 tons, at an estimated cost of $4 000 000 to $6 000 000.

Bruges Canal.—The old-time commercial prestige and importance of Bruges has been gradually but completely destroyed by the silting up of its communication with the sea, and it is now proposed to construct a ship canal direct to the sea, a distance of 7½ miles. The proposed section of the canal is: bottom width, 66 feet; width at water surface, 203 feet, and depth, 23 feet. The estimated cost is about $5 000 000.

Paris-Boulogne Canal.—This canal is proposed for vessels of 600 to 800 tons. Its width would be 197 to 230 feet, increased to 262 feet at passing places, and the depth 13 feet.

Italian Canal.—In the summer of 1888 Signor Broca completed the survey of a canal across Italy, to save the long journey around Cape Lucca. The line of the canal extends from Fano, on the Adriatic, to near Castro, on the Mediterranean. Length, 180 miles; proposed width, 33 feet, and depth, 40 feet. Estimated cost, $100 000 000, and time for completion five years. In constructing this canal it would be necessary to drain two lakes. It is claimed that the canal would be of great value to the whole of southern Europe.

Baltic-Black Sea Canal.—Within the past five or six years the project for a ship canal from the Danube near Vienna through Moravia and Austrian and Prussian Silesia to the Oder near Breslau has attracted considerable attention, and has been carefully discussed at Berlin and Vienna. The distance in an air line is 200 miles and the estimated cost of a canal capable of passing large war vessels is put at about $37 000 000. The project has been reported as entirely feasible, and it is said that a preliminary credit for conducting the surveys has been applied for.

It is proposed that three-fifths of the expense should be borne by Austria and the remainder by Germany.

The number of vessels using the canal, it is claimed, would be three times as great as the number at Suez.

Don-Volga or Black Sea-Caspian.—The route of the long-talked-of canal, plans for which are said to have been drawn up in the time of Sultan Selim, is to be from Serepta, on the Volga, to Tzaritzine, on the Don, a distance of 53 miles. It will accommodate vessels 230 x 40 feet of 500 to 600 tons, which it is expected can make the trip in seventy hours.

The estimated cost of the canal is $14 000 000, not including administration, discounts, etc. Of this sum, $8 000 000 is for excavation, $4 000 000 for locks, and $2 000 000 for bridges, buildings, etc. The total excavation is estimated at 35 000 000 cubic yards. The deepest cut is 128 feet.

Perekop Canal.—This canal as projected will cut the Isthmus of Perekop, which unites the Crimea with the mainland, and unite the waters of the Gulf of Perekop and the Azof Sea.

It will be 70 miles long, 65 feet wide and 12 feet deep, and the estimated cost is $40 000 000. It is thought that it can be constructed in

four or five years, and it is claimed that it will shorten the voyage between Odessa and Sea of Azof ports 295 to 434 miles, enable vessels to avoid the dangerous navigation of the Straits of Kertch, and greatly benefit the salt, mineral, grain and fuel producing districts of south-eastern Russia.

A company is now said to be awaiting Russian sanction to build the canal.

Jordan or Palestine Canal.—The general features of this project were as follows : A canal 25 miles long, about 200 feet wide and 30 feet deep would be cut from Acre, on the Mediterranean, to the valley of the Jordan, north of Lake Tiberias.

The maximum depth of the cut would be 285 feet.

A second canal 67 miles long, and presumably of the same dimensions, would be cut from the head of the Gulf of Akabah to the south end of the Dead Sea Valley. The deepest cut on this section of canal would be 728 feet.

The valley of the Jordan and the Dead Sea, portions of which are 1 300 feet below the sea level, would then be flooded, obliterating the Jordan, Dead Sea, Sea of Tiberias and several hundred square miles of land, and forming a lake about 147 miles long and 10 miles wide, and the canal would be complete. The total distance from sea to sea is 240 miles. The estimated cost was from $40 000 000 to $100 000 000, and the estimated time of passage as four hours shorter than the Suez route.

Numerous advantages were claimed for this project, among others that it would be the fulfillment of the prophecy in Ezekiel. "Chinese" Gordon was a supporter of it.

As the origin of this project was entirely English, and as it was prominently agitated just at the time when the question of the enlargement of the Suez Canal was being discussed and England was endeavoring to obtain from M. de Lesseps a reduction in tolls and a greater share in the management at Suez, and nothing has been heard of it since, it is open to the suspicion that it was used merely to obtain as good terms as possible.

Syrio-Persian Canal.—The general project for a canal from the Persian Gulf to the Mediterranean was laid before the French Academy of Sciences in the winter of 1886–87, by a French engineer, without, however, any estimate of cost. The line of the canal as indicated is from Antioch up the Orestes, thence by tunnel through the mountains to the Euphrates, then utilize that river to Babylon, thence by canal to Bagdad, then down the Tigris to the Gulf. It is claimed that this canal would shorten the route between Europe and Asia three days.

Isthmus of Malacca Canal.—The project for this canal was vigorously agitated by the French in Siam in 1882–83, and in the latter year M. de Lesseps asked the King of Siam for a concession.

This canal would unite the Bay of Bengal and Gulf of Siam near Kraw, *via* the bed of the River Tayons.

Its length would be about 66 miles, and it is claimed it would save 500 miles of dangerous navigation between New York or Liverpool and the ports of China. Estimated cost, $20 000 000.

Ceylon-Indian Canal.—This project is to cut a channel through the island of Ramisseram, lying between Ceylon and India, by which it is said a sea voyage of 300 to 400 miles will be saved.

Projected Canals.—At Home.

Panama Canal.—The idea of a canal at Panama is of equal antiquity with that of Nicaragua. The two projects may be said to be twins.

The first actual survey of the Panama line seems to have been made in 1828, but nothing came of it. In 1843-44 M. Napoleon Garella surveyed a line across the Isthmus, and a French company was organized, and preparations made to commence the work, but wars in Europe interfered, and the project fell through. In 1875 a line was surveyed across the Isthmus by Captain Lull, United States Navy, under orders from the Navy Department, and plans and estimates for a lock canal were presented.

In 1876-77 Lieutenants Wyse and Reclus, of the French Navy, surveyed several lines, and in March, 1878, Lieutenant Wyse obtained a concession from the Columbian Government. A company was then formed, with M. de Lesseps at its head, to construct the canal, and after the preliminary arrangements were completed, work commenced in 1881.

Several plans for this canal were discussed, viz., with locks, with a tunnel, and a thorough cut, the last plan being finally adopted. The length of the canal is 47 miles, the bottom width 22 meters in earth and 24 meters in rock, the surface width 50 meters in earth and 28 meters in rock, and the depth 8.5 and 9 meters. The deepest cut is 386 feet, and the total amount of material to be removed was estimated at first at 46 000 000 cubic meters; later at 105 000 000 cubic meters, and still later, 1885, at 151 000 000 cubic meters, which last figures are probably still below the mark.

The original estimate of the cost of the canal was $120 000 000, the time for its completion eight years, and it was expected that 5 000 000 to 6 000 000 tons of traffic would use the canal.

Under the stimulus of M. de Lesseps' wonderful energy and great prestige the stock of the company was rapidly taken, and great quanti-

ties of plant and material were shipped to the Isthmus, a magnificent "installation" was put in commission, and the work went merrily on. Almost at the outset, however, obstacles which had been pointed out by prominent engineers were encountered, and the work did not progress as rapidly as had been expected. Several additional issues of bonds were made without dampening the enthusiasm, until in 1886 many intelligent people, who had hitherto believed in the project, became doubtful as to its success. This feeling spread, and became general in 1887, when it was shown conclusively that about $150 000 000 had been expended, and less than one-fifth the total amount of excavation had been completed, and that the company could raise no more money except at ruinous discount.

To meet this state of affairs the plans were changed provisionally to a lock canal, with locks to be gradually lowered to sea level after the canal was opened. This change very materially reduced the amount of excavation yet to be done, and was not without its effect in restoring confidence in some quarters.

This effect, however, soon wore off, and after a series of desperate financial moves to raise money last summer—among others a grand lottery scheme—the failure of the company to float an additional issue of bonds, even at a ruinous discount, gave the project its death blow, and after a few months of unavailing struggles, it collapsed finally and completely during the past winter, with obligations amounting to over $450 000 000, and after having spent some $250 000 000 in hard cash in the removal of some 50 000 000 cubic meters of material, about one-third the total amount. The laborers employed on the work have been sent home by their respective governments, and the Panama Canal is a thing of the past.

As an engineering work it has not been especially interesting, none of the really serious engineering problems connected with its completion having been touched as yet.

It is interesting, however, as showing the blind infatuation with which the *ipse dixit* of one man may be followed in the face of all facts and experience, and the results of beginning a great work without sufficient or accurate information.

It may be taken for granted that the Panama Canal will never be completed.

Delaware-Chesapeake Canal.—During 1879–82 the Government sur-

veyed three principal routes for a ship canal to connect the Chesapeake and Delaware Bays, and since then the project has been more or less prominently before the public, and a company was formed to construct the canal, but as yet no work has been done.

Of the three routes surveyed, the one known as the Sassafras is the favorite.

The length of the canal by this route is 30 miles from bay to bay, of which distance 14 miles will be obtained by deepening and widening streams, and the remaining 16 miles will be thorough cut.

The proposed section of the canal is: bottom width, 90 feet; surface width, 171 feet; depth, 27 feet.

No locks except tidal locks. The cost is variously estimated at from $6 500 000 to $11 500 000, and the time for completion is put at four years.

The canal would save 215 miles between Baltimore and New York and other Eastern and European ports, and 286 miles between Baltimore and Philadelphia.

It is anticipated that the canal would attract at least three-fourths of the tonnage of Baltimore, or from 5 000 000 to 10 000 000 tons.

From a military point of view this canal would be of great importance.

Niagara Falls Canal.—Several surveys and plans for a ship canal from Lake Erie to Lake Ontario have been made within the past thirty years, and two powerful causes push the project to the front every now and then: 1st, The very natural desire to have a canal of our own between those lakes; and 2d, the fact that the Welland Canal, with its 14 feet depth, is not deep enough to accommodate modern lake traffic, a fact which will be doubly emphasized when the improvements at St. Mary's and St. Clair have been completed and a depth of 20 feet obtained.

A recent project is for a canal 20 feet deep, to accommodate vessels of 3 000 tons. The length is about 25 miles and the estimated cost $18 000 000. An alternative route of 18 miles would cost about $1 000 000 more.

This canal seems more than likely to become an accomplished fact in the not distant future.

Florida Canal.—The project for a ship canal across Florida has been more or less continuously agitated during the past ten years or more, and in 1883–84 it looked as if the work would be actually undertaken.

A charter was obtained, a company organized and surveys made, but nothing came of it.

Starting from the St. John's River, just above Jacksonville, the canal would cut across to the Suwanee River, on the Gulf Coast. Its total length would be 137½ miles, the deepest cut 143 feet for a short distance, and the proposed dimensions were a width of 230 feet and a depth of 30 feet, sufficient to permit 3 000-ton vessels to pass without sidings. It was expected the canal could be completed in three years, and the estimated cost was $46 000 000.

The canal would enable vessels to avoid the navigation of the Strait of Florida, and would save in distance

Between New York and New Orleans	500 miles.
" " Pensacola	600 "
" New Orleans and Liverpool	412 "

Delaware-New York Bay Canal.—This project contemplates the enlargement of the Delaware and Raritan Canal sufficiently to permit its use by large vessels.

This canal, with the Cape Cod Canal, the canal from the Delaware to Chesapeake Bay, and the Dismal Swamp Canal, would form a grand system of inland navigation, which would offer an almost air line route to the coasting trade between Boston, New York, Philadelphia, Baltimore, Norfolk and the Carolina Sounds.

Such a system of navigation could not be duplicated in either hemisphere, nor its commercial and military importance be overestimated.

The military advantages of this project have recently been made the subject of a very instructive report by Admiral Luce, U. S. N., in which he points out the facilities such a canal would offer for the rapid concentration of war vessels at any point, either for attack or defense, and the complete bar it would present to any effectual blockade of any of our great bays or ports.

Other home projects, comprising some in the earliest embryo stage, some of inconsiderable importance, and some in regard to which it has been impossible to learn more than the name, are as follows:

Lake Borgne Canal.—From Lake Borgne to the Mississippi River; length, 12 miles; length of locks, 350 feet; estimated cost, $450 000. Will save coast trade east of New Orleans a voyage of 265 miles.

St. Clair-Lake Erie.—From Lake St. Clair to Lake Erie, Canadian territory.

Cincinnati-Lake Erie.—Two routes proposed—one from Cincinnati

to Toledo, and one *via* Zanesville to Cleveland. Preliminary estimate of cost of enlarging present canals about $28 000 000.

Fresno-San Joaquin River.—Surveys said to have been made, and the canal is to be of size to permit stern wheel steamers to run through from San Francisco. Estimated cost $3 000 000.

Lower Michigan.—From Saugatuck to Detroit *via* Kalamazoo River; length about 178 miles; width, 112 feet on the surface, 80 feet on the bottom; depth sufficient to accommodate vessels of 1 500 tons; six to eight locks. The canal would give an almost air line route from Chicago to New York, saving several hundred miles.

Upper Michigan.—The project for this canal is undoubtedly the outgrowth of the crowding of the St. Mary's Canal by the rapidly increasing lake commerce.

The proposed route is from Bay Autrain, on Lake Superior, to Little Bay de Noquet, on Lake Michigan. Length, 36 miles; two locks; estimated cost about $5 000 000, or a little more than the estimated cost of the proposed improvements at St. Mary's. The distance between Duluth and Chicago would be reduced 271 miles.

Lake Erie-Ohio River.—This is a project to obtain a deep water navigation from the Great Lakes to the Gulf of Mexico. The probable route would be from Beaver, on the Ohio, 28 miles below Pittsburgh, *via* Newcastle and Conneaut Lake to Erie, Pa. Distance, 136 miles; summit, 416 feet above the Ohio and 509 feet above Lake Erie.

Harcourt divides ship canals into three principal classes, and one supplementary class, viz.:

First.—Ship canals with locks and a summit level.

Second.—Ship canals passing through low-lying districts, and with only a regulating lock at each end.

Third.—Ship canals without locks, and of world-wide importance.

Fourth.—Ship canals from inland ports to the sea, and lateral ship canals in place of river navigation.

In an engineering sense the division into canals with locks and those without locks would seem to be a sufficient refinement.

A classification based upon the causes which lead to the inception and execution of such canals suggests itself, viz.:

Commercial Canals, originating in the demand of cities or regions, unfavorably situated by nature, for an outlet for their products; or in the struggle between rival cities or states for commercial precedence or perhaps even existence, as the Manchester, St. Mary's and Amsterdam canals.

Military Canals, originating in a nation's military and strategic exigencies or ambitions, as the Holstein Canal.

Interocean Canals, originating in the imperative demands of the commerce of the world, as the Suez and Nicaragua Canals.

Commercial canals may, by force of circumstances, become of temporary strategic importance, and military canals are certain to be of more or less commercial utility.

Interocean canals are the highest class. Aiding no one nation at the expense of another, they benefit every country that owns a ship.

Naturally in time of misunderstanding they become of inestimable strategic value to that nation that can control one of them. There are but two locations for such canals—one in each hemisphere, Suez and Nicaragua; one is completed, the other in course of construction.

After making all allowance for the fashion set by the completion of the Suez Canal, and the added impetus given by the commencement of the Panama Canal, eight years ago, to all kinds of projects for ship canals, many of which the recent catastrophe at Panama will cause to drop out of sight, we may safely say that the ship canal has come to stay and to become a powerful commercial and political factor. The next few decades are certain to see wonderful results in that direction.

The completion of the Nicaragua Canal will leave no more worlds to conquer in the class of interocean canals. The universal impetus it will give to commerce, together with the already active tendency in the direction of ship canals to give inland ports a direct and unobstructed communication with the sea, will probably for a time concentrate the activity in ship canal construction to works of that class.

The completion of many of these, and the continued growth of ocean commerce and its ever-increasing demand for shorter routes, will then result in the construction of canals of the character of the Corinth, Italian, Isthmus of Malacca, and Delaware-New York Bay canals, until every sea and ocean route will have been reduced to its minimum length. And though we may hardly expect to reach the state which recent astronomical observations are said to have shown upon our neighbor Mars, where a perfect network of canals, from 30 to 80 miles wide and some of them 1 000 miles long, appears to traverse the planet in every direction, it perhaps is not too wild a flight to anticipate the time when every maritime nation of importance will have, as one of its most important adjuncts of military offense and defense, a ship canal, for the rapid concentration of its huge floating fortresses at different parts of its coast.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

420.

Vol. XXI.—August, 1889.

THE VICKSBURG SETTLING BASINS.

By CLARENCE DELAFIELD, M. Am. Soc. C. E.

Vicksburg, Miss., has always been considered a difficult point to supply with water, and, being called upon to design and construct works for this place, it became necessary to make a careful study of the sources from which the supply could be secured. By careful borings I ascertained that water could not be obtained from subterranean sources at any reasonable expense.

Centennial Lake, the original river, now cut off by a wash-out, is the receptacle of the drainage not only of the City of Vicksburg, but also of a large area of swamp, and is unfit for use.

The only source of supply remaining was the Mississippi River. This turbid water is thoroughly enjoyed by those who are accustomed to it, and its muddy appearance seems to offend none of the old citizens of the many cities and towns consuming it; but to those unfamiliar with its use, the appearance of the liquid is disgusting, and a clear, bright water is insisted upon.

The different conditions existing in the Mississippi River demand thoughtful care in selecting the proper treatment to meet the requirement of clear water.

When the river is low, and the current has little velocity, the amount of material held in suspension is very small, but in high stages of the river, when the banks are constantly caving, the quantity of solids carried by the stream is greatly increased. Through the kindness of Colonel L. H Gardner, Superintendent of Water Works, New Orleans, La., I am enabled to give the result of tests made by him for thirty-nine weeks during the past year. The table exhibits the amount of solids in suspension in the Mississippi River water, expressed in grains per gallon:

Week.	Grains, Per Gallon.	Week.	Grains, Per Gallon.	Week.	Grains, Per Gallon.	Week.	Grains, Per Gallon.
1	1 688	11	88	21	108	31	33
2	297	12	51	22	83	32	79
3	74	13	137	23	164	33	140
4	53	14	183	24	173	34	80
5	164	15	159	25	87	35	120
6	1 650	16	193	26	80	36	73
7	60	17	178	27	77	37	34
8	100	18	166	28	34	38	13
9	162	19	75	29	19	39	45
10	104	20	201	30	14		

These figures show the wide fluctuations which exist in the amount of solids carried by the stream, and give a fair idea of the ever-changing conditions to be contended with.

If this water is allowed to stand at rest in a glass, the sand and coarse particles are almost immediately deposited, the larger part (by weight) of the suspended matter being precipitated in one day, leaving a certain depth at the surface fairly clear. The second day the water is clear to a greater depth, and in from four to ten days most of the suspended matter has been deposited. What remains is such an impalpable powder that it continues in suspension for a period far beyond any experiments I have made; it is, however, readily removed by a filter.

But another condition exists in the lower Mississippi River, that is, a stain caused by the overflow of swamps during floods at periods of high water. This matter is in solution, and cannot be removed by filtration unless previously treated by chemicals.

With these conditions, it is evident that to remove the matter in suspension, the water must be at rest, and that the finest particles can only be taken out by filtration.

Basins that would permit the constant inflow and outflow of water for daily use, with a minimum of disturbance, were desirable, and to accomplish this result I designed the works illustrated in the accompanying plan, Plate XXVIII.

The water is pumped directly from the river into the influent basin; from here it passes through seep-holes in Dividing Wall *A*, into Settling Basin No. 1, in slow, divided streams, without any tendency to produce circular currents or eddies. In Basin No. 1 by far the largest part of the sedimentation takes place, and the motion of the water is very slight.

To introduce the water into Basin No. 2 with the least possible disturbance, it is carried over the top of Dividing Wall *B* for its full length, drawing only the clearest surface water, and is then conveyed by interior passages to within 3 feet of the bottom of Basin No. 2. This thin stream, when delivering a million gallons of water per diem, flows at the rate of one-eighth gallon per second per lineal foot of wall, and the discolored water passing from Basin No. 1 to No. 2 has not sufficient current to raise much of the matter still held in suspension—hence the surface of the water is fairly clear.

To remove the slight cloud remaining, the water passes over the top of Wall *C* into Basin No. 3, then through the sand filter *D* into clear water basin No. 4.

The apertures in the filter are 4½ inches wide, and of sufficient height to allow the sand a slope of at least three to one, this height varying with the thickness of the walls; the current is so slight that no wash or disturbance of the sand takes place.

When the sand is fouled by continued use, it can readily be removed by washing it out of these apertures by a hose into Basin No. 3, and then the filter can be replenished with clean sand at the top. It will be remembered that this filter has but a slight duty to perform, as the amount of matter to be removed is infinitesimal.

Ordinarily, the water is now found clear and admirable for use, but at times, when the stain of the swamps is in solution, a small amount of either alum or perchloride of iron is found necessary to convert it into a form which can be removed by precipitation or filtration. A solution of alum is now used, which is introduced in absolute quantity from a tank connected by a pipe to the suction main of vertical pumps, thus intimately mixing it with the entire body of water, and presenting

every portion to its chemical action. The result is absolutely clear water.

The percentage of alum used is about one grain to the gallon, and it is entirely inert and harmless, even if not doing its proper duty.

The perchloride of iron is more energetic and has the effect of precipitating all matter in suspension within forty-eight to sixty hours, and is valuable in allowing a diminished area of settling basin, and leaving less duty for the filter. To those who have used filters this feature will be highly appreciated, as many a filter gets credit for the duty already performed by alum or perchloride of iron.

For the removal of matter deposited, I have designed the bottom of Settling Basin No. 1 with five valleys, each ending in a 10-inch outlet pipe closed by a gate. Basin No. 2 having but a slight deposit of very light material, has but one valley, with corresponding outlet pipe and gate. Basins Nos. 3 and 4, as a matter of precaution, and to wash out fouled filtering material, are each provided with an outlet and gate.

These outlet or drain pipes join one main sewer and empty into the river at a point down stream from the intake. For the purpose of removing the material deposited, a hose is attached to the force main to stand pipe, and with water under a pressure of 90 pounds, the deposit is rapidly removed to and through the drain pipes, and at small cost.

As it will take some years of use to determine the rate of deposit, and as the filter, with its small duty of removing inert, inorganic matter, will only be renewed at long intervals, it is difficult to estimate the cost of operating the settling basins and filter in relation to the amount of water pumped. I believe it will be small as compared with the cost of the large amount of water used in cleansing the ordinary filters, and the increased coal bills incurred in obtaining the additional pressure required to pump through the obstruction offered by such filters.

These works have now been in use for several months, and the water delivered to consumers is giving perfect satisfaction; it is the first adaptation of well known ideas as to settling basins and filtration direct.

The cost of the plant is about $17 500, but of course on a larger scale would be much less proportionately; it is asking too much of filtration alone to produce the same result as economically.

The fundamental principles of this design are, first, to avoid circular or direct currents of any velocity, or at least to reduce the same to a

minimum; second, to carry the surface water, as being the clearest, from one basin to that next adjacent; third, to lead the water from one basin to the lower portion of the next, where, on account of the absence of currents, the suspended matter would have no tendency to rise, thus leaving the superficial water clear to pass into the next basin.

A fence was erected, inclosing the basins, in order to prevent any disturbance of the water by wave action and currents caused by the wind.

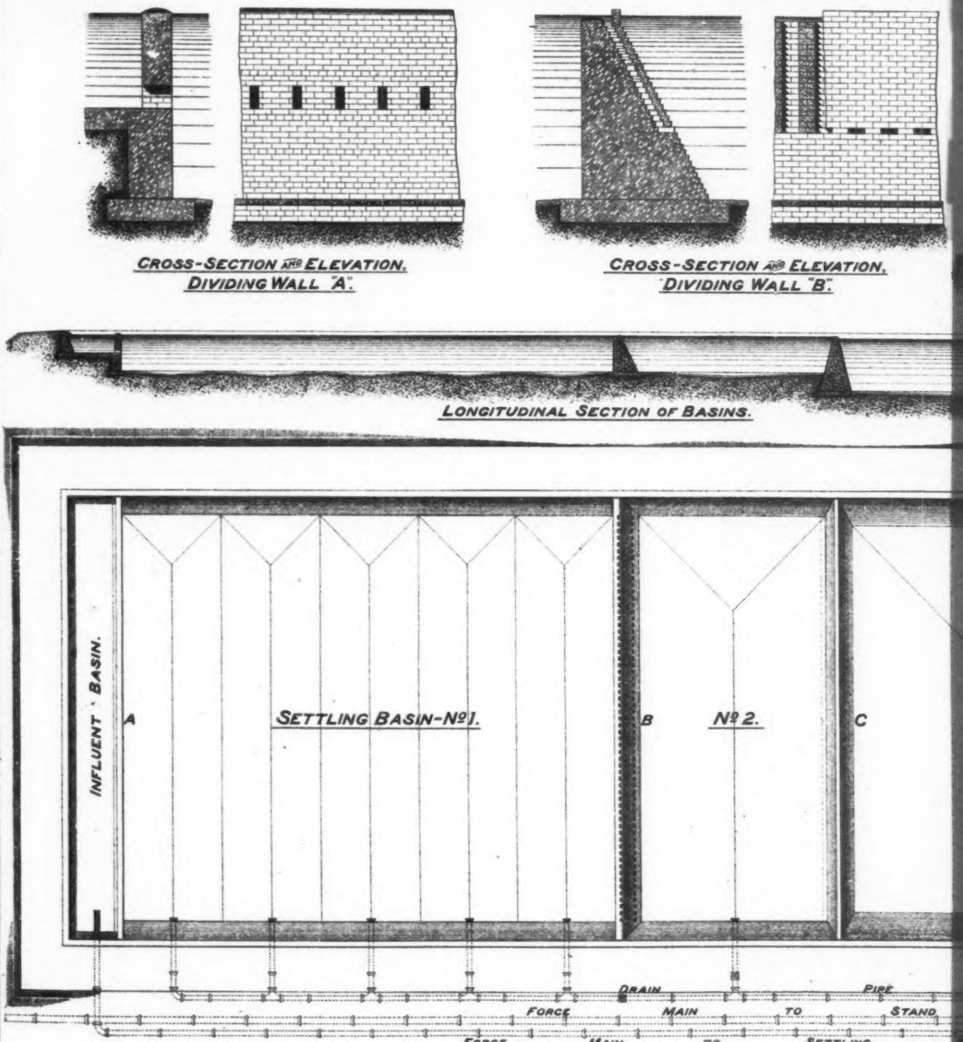
I would advise, in any future constructions, the use of a permanent system of piping, with numerous outlets of small aperture, directed toward the drain pipes, for the purpose of washing the deposited mud from the basins and the fouled sand from the filter. These pipes, being attached to the main system of water supply, and under that pressure, would rapidly do the work required, carrying the silt and sand into the river. This would unquestionably save labor in cleaning the basins, at the cost of pumping the amount of water required. Coal used in making steam for power is undoubtedly cheaper than the labor of man.

Objection may be made that puddle was not used instead of brick walls in this design. The answer is that a puddle clay could not be found in the locality, as all clays in the neighborhood contain a large percentage of sand, rendering them pervious and unfit.

Slopes covered with brick or béton I have always found uncertain and difficult to render water-tight; they also retain a large proportion of the deposited material; for these reasons I have preferred brick walls.

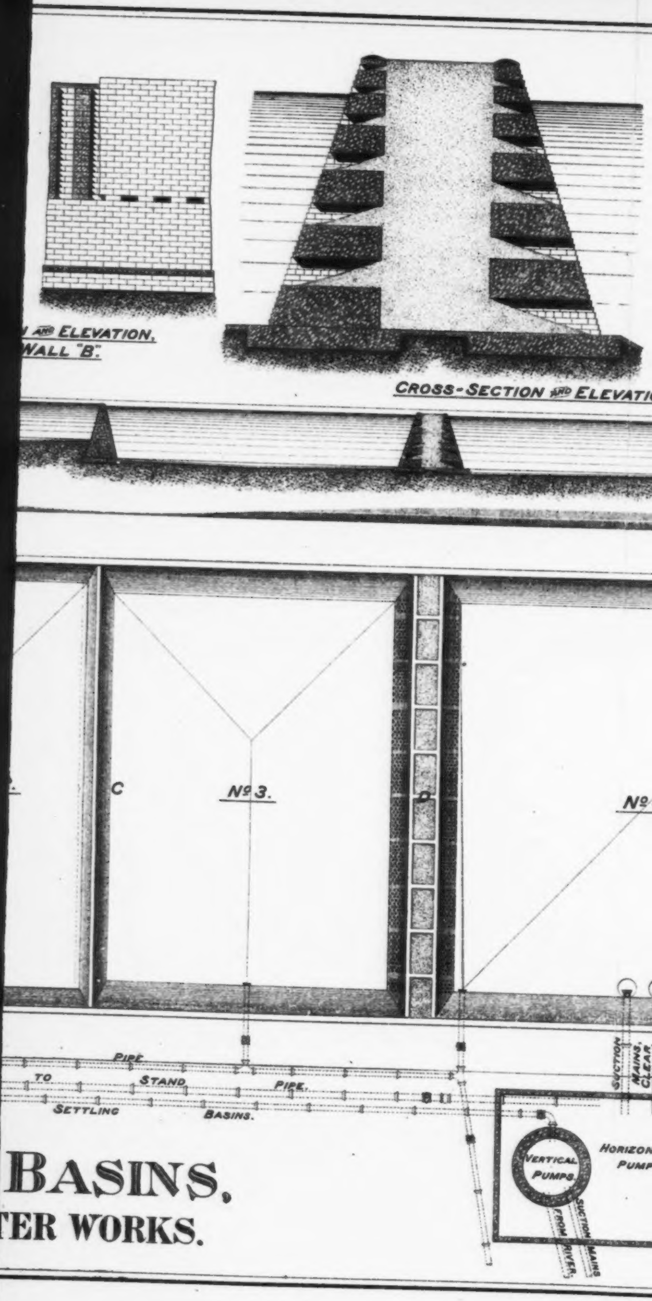
A limited experience demonstrates that these basins easily give 500 000 to 600 000 gallons clear water, pumping only ten hours *per diem*, and I believe their capacity for twenty-four hours' use *per diem* to be over one million gallons.

As the average amount of material carried in suspension is about 186 grains per gallon, I estimate the deposit at 265 cubic feet per million gallons, or 38 million gallons per foot in depth of deposit in Settling Basin No. 1; hence, cleaning the basins once each month will be sufficient, and this can easily be done during a night.



SETTLING BASINS

VICKSBURG WATER WORKS.



N AND ELEVATION,
WALL "B".
CROSS-SECTION AND ELEVATIO
C
Nº 3.
D
Nº
PIPE
TO
STAND
PIPE.
SETTLING
BASINS.
SUCTION
MAINS, CLEAR
VERTICAL PUMPS.
HORIZON
PUMP
SUCTION MAINS
FROM RIVER.
BASINS,
TER WORKS.

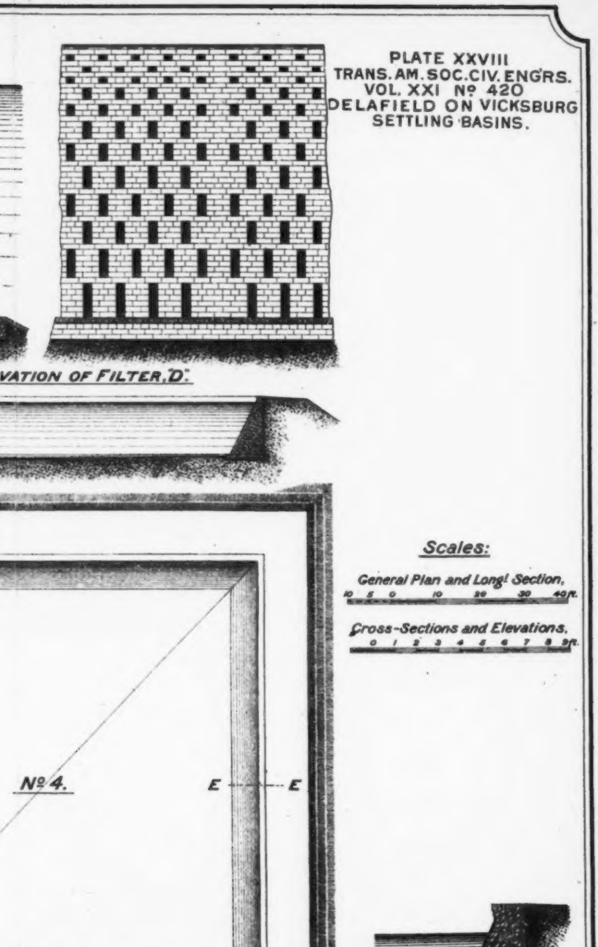


PLATE XXVIII
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XXI Nº 420
DELAFIELD ON VICKSBURG
SETTLING BASINS.
VATION OF FILTER "D".
Scales:
General Plan and Long! Section,
10 5 0 10 20 30 40 ft.
Cross-Sections and Elevations,
0 1 2 3 4 5 6 7 8 9 ft.
Nº 4.
E
E
SUCTION
MAINS, CLEAR WATER.
HORIZONTAL PUMPS.
BOILER ROOM.
COAL ROOM.
STORE ROOM.
SMOKE STACK.
CROSS-SECTION E-E.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

421.
Vol. XXI.—August, 1889.

MAXIMUM RATES OF RAINFALL.

By DESMOND FITZGERALD, M. Am. Soc. C. E.

The diagrams accompanying this paper show the principal maximum rates of rainfall at Chestnut Hill Reservoir, Boston, between the years 1879-89. (Plates XXIX, XXX, XXXI, XXXII, XXXIII.)

Previous to this time the observations were of the ordinary kind, viz., those taken from a simple rain gauge which was weighed after each storm. The writer had been impressed for some years with the importance of possessing an automatic and continuous record, but none of the gauges upon the market seemed to possess all the qualities which were desirable; accordingly, a gauge was designed and built in 1878 to plot a profile of all rains, and the following diagrams are tracings made directly from the record sheets of this gauge. It will be noticed that the vertical scale is 2 inches of paper to 1 inch of rainfall. The scale was doubled in this manner to admit of close approximations to hundredths of an inch in readings by the eye. The horizontal scale of hours gives an inch of paper to the hour. The cylinder on which the sheets are wrapped is sufficiently large to record 6 inches of rainfall, but larger amounts can

easily be plotted by drawing off the water from the receiving tank. A description of the gauge has already been printed in *Engineering News*, May 31st, 1884.

The figures on the margins of the diagrams give in each case the total rainfall, as recorded by a standard gauge, placed with its rim one foot above the ground. The time of the beginning and ending of the rain is given, the time of beginning and ending of the "down pour," and also the proper correction for the elevated gauge due to its height above the ground. It is already a well-established fact that the higher we rise above the ground the less rain we can collect, unless special construction is resorted to. This result is probably due to the fact that the velocity of the wind increases from the surface upwards so materially as to affect the amounts collected. The receiver of the self-recording gauge being placed on the roof of a small building about 25 feet above the ground, it becomes necessary to make the proper correction for altitude, which is done by taking the ratio of each storm in the upper gauge to that in the ground gauge and applying this percentage to any particular portion of the storm. Generally the down pour portion of the storms only is given, as, for our particular purpose, it is desirable simply to show the maximum rates.

As the question of the proper sizes for sewers has recently been occupying the attention of the Society, these maximum rates have been selected from the records of the past ten years in the hope that they may be of service as an index of what may be expected in the vicinity of Boston.

These storms are not necessarily those which have given the greatest amounts of rainfall, or caused the most wide-spread damage. This class of rains, as far as applicable to drainage areas of any extent, is generally spread over several days, and may not give a large rate per hour at any portion of its profile.

In examining the diagrams, it will be noticed that the rain which gave the most vertical profile, and consequently the greatest maximum rate, occurred on July 18th, 1884, and yielded at the level of the ground 0.70 inches in five minutes. (Plate XXXI.) The rain literally fell in a flood, but its duration was short, and it was a local shower, probably confined to an area of a few hundred acres. This fall, which is at the rate of 8.4 inches per hour, might almost be doubted, but it has also been observed elsewhere.

A rate of 9.6 inches per hour, lasting for six minutes, has been recorded in Washington, D. C.

The rain of July 20th, 1880 (Plate XXX), yielded 1.46 inches in forty minutes.

The storm of August 21st, 1888, recorded on Plate XXXIII, was remarkable, extending, as it did, over a wide area, and yielding 3.22 inches in three hours and twenty minutes. Near the end of this storm it rained 0.85 inches in twenty-two minutes, which is at the rate of 2.3 inches per hour.

During some of the winter months the self-recording gauge has not been in use, and from this cause the interesting rain of February 10th to 14th, 1886, escaped the record. The experience of the writer on the Boston Water Works covers the period 1873–89, and during this time there have been but two great freshets at the sources of supply. Although foreign to the immediate purpose of this paper, a few words in regard to these two storms may not be out of place. The second of these was the one above alluded to. The first took place in March, 1876. There was a considerable amount of snow upon the ground, and on this snow a warm rain of 2.27 inches fell on March 21st, 1876.

This caused a freshet, but was farther reinforced on March 25th by another rain of 3.20 inches, which carried the flow of the Sudbury River up to a maximum rate for a fraction of a day of nearly two thousand million gallons in twenty-four hours (drainage area, 76 square miles.)

The following is an abstract from a report by the writer to the Boston Water Board upon the other freshet of 1886:

"On February 10th there was quite a body of snow upon the ground, probably equivalent to 2 inches of rainfall. At 7 P.M. on the above day rain began to fall and continued until noon of the 13th. The total rainfall upon the Sudbury River water-shed was 4.64 inches, but adding the snow on the ground would increase this amount to over 6 inches. The greatest freshet that I have ever seen on the works followed. The snow melted but slowly at first, or the flow of the streams would have been even larger than it was. On the 13th the yield of the river was very nearly 2 000 000 000 gallons in twenty-four hours. The maximum rate of yield was from 7 A.M to 12 M. of the 13th, and was at the rate of 2 136 000 000 gallons in twenty-four hours. The total yield of the 76 square miles from the 11th to the 18th inclusive was 6 505 000 000 gallons. The weather during the freshet was mild and the snow was all

melted from the ground. The following shows the yield for each day:

February	11th	149 600 000	gallons.
	12th	918 600 000	"
	13th	1 994 700 000	"
	14th	1 287 300 000	"
	15th	837 800 000	"
	16th	531 000 000	"
	17th	428 700 000	"
	18th	357 400 000	"

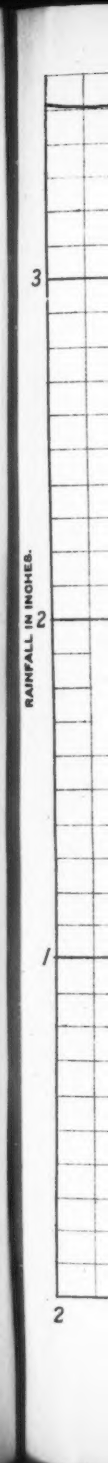
Other important data in regard to this storm may be found in the report of the Stony Brook Commission. Emil Kuichling, M. Am. Soc. C. E., in a recent paper before the Society,* has given some abstracts from this report, and it will be unnecessary to repeat the data here.

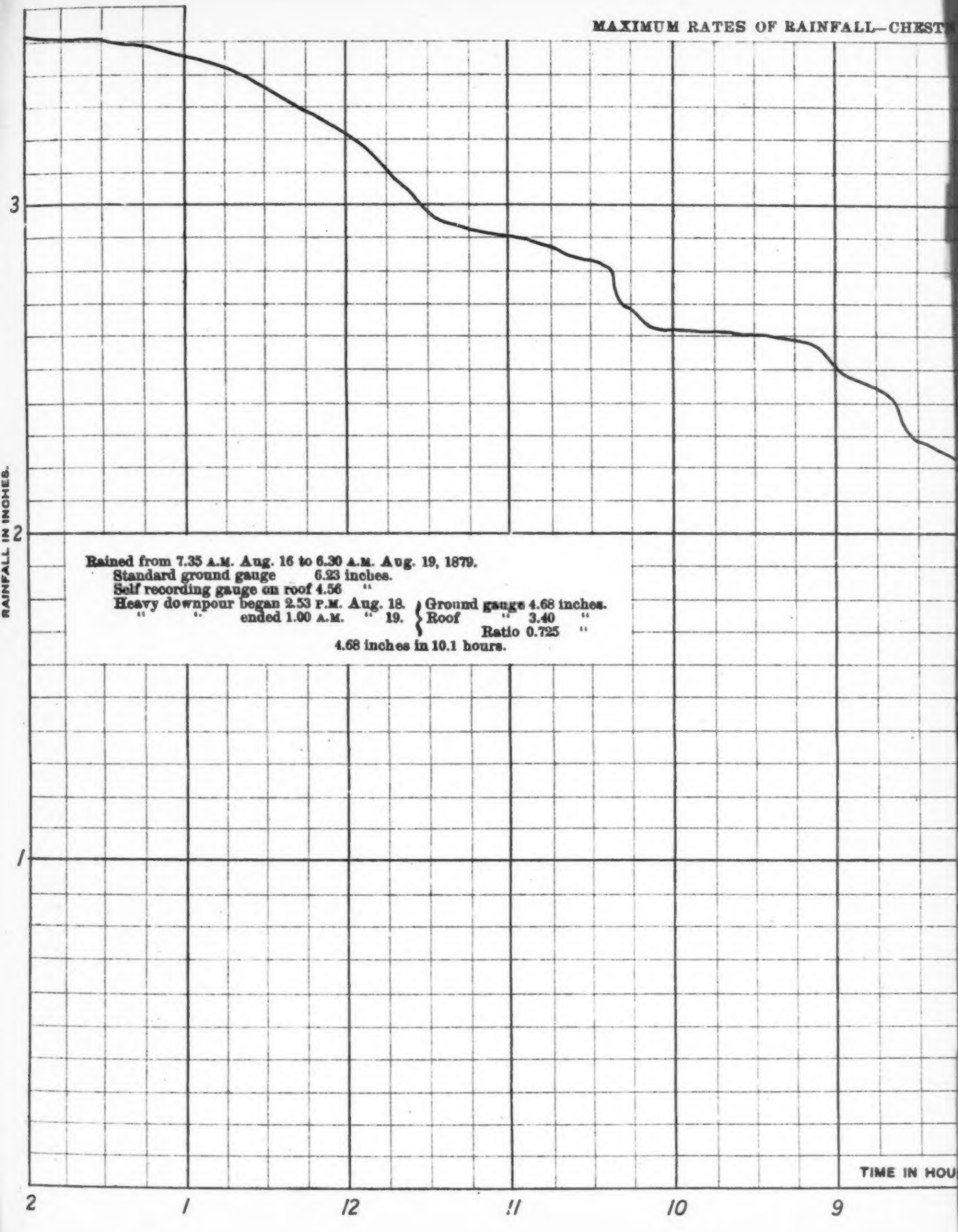
Larger rainfalls than these two cases cited have often occurred during other portions of the year when the evaporation and percolation have prevented the water from getting to the streams, but they have never happened to occur in recent years on the Boston Water Works, when the ground was frozen, or when there was an accumulation of snow, but in designing waste weirs and channels, it is evident that the engineer must provide for just this contingency, which is almost certain to occur sooner or later.

In urban districts the problem is, of course, a different one. Here percolation and evaporation may not enter materially into the question, but it is extremely necessary for the engineer to have some data like that taken from self-recording rain gauges to guide him in proportioning the capacities of his sewers. Considering the importance of the subject, it is a matter of considerable wonder that more of these gauges are not in use.

Certainly, every large city should have one or more, properly located and in competent hands for maintenance. Records of this kind, covering long periods, will prove of value for many purposes connected with the practice of the engineer.

* Transactions, Vol. XX, p. 1, January, 1889.




MAXIMUM RATES OF RAINFALL—CHEST
RAINFALL IN INCHES.
3
2
1
Rained from 7.35 A.M. Aug. 16 to 6.30 A.M. Aug. 19, 1879.
Standard ground gauge 6.23 inches.
Self recording gauge on roof 4.56 "
Heavy downpour began 2.53 P.M. Aug. 18. " " ended 1.00 A.M. " 19.
Ground gauge 4.68 inches.
Roof " 3.40 "
Ratio 0.725 "
4.68 inches in 10.1 hours.
TIME IN HOU
2
1
12
11
10
9

RAINFALL—CHESTNUT HILL RESERVOIR—BOSTON WATER WORKS.

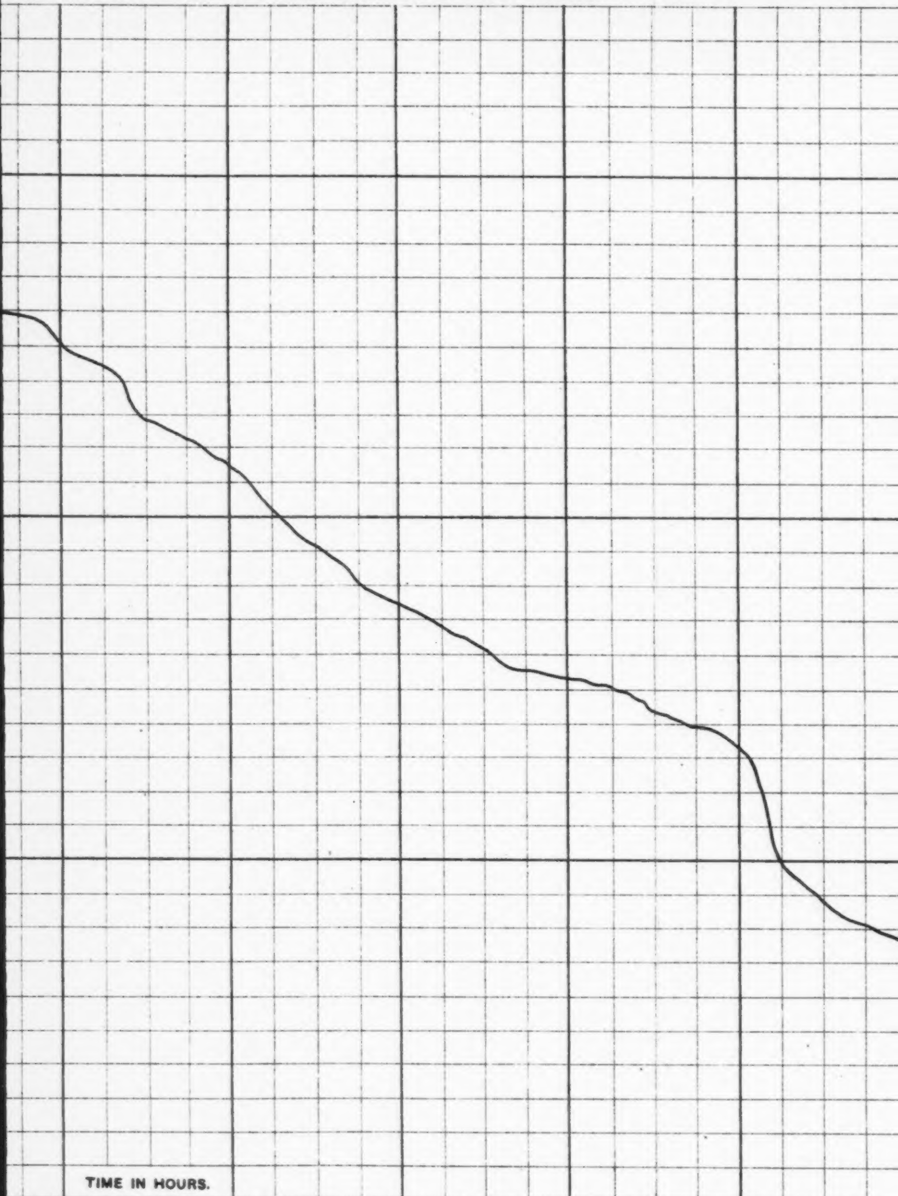


PLATE XXIX
TRANS. AM. SOC. CIV. ENG'RS.
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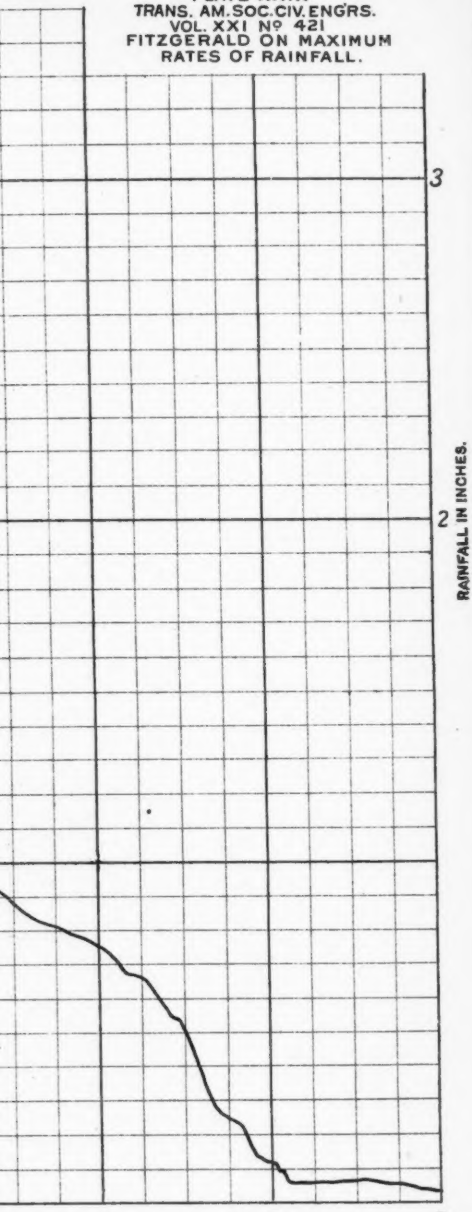
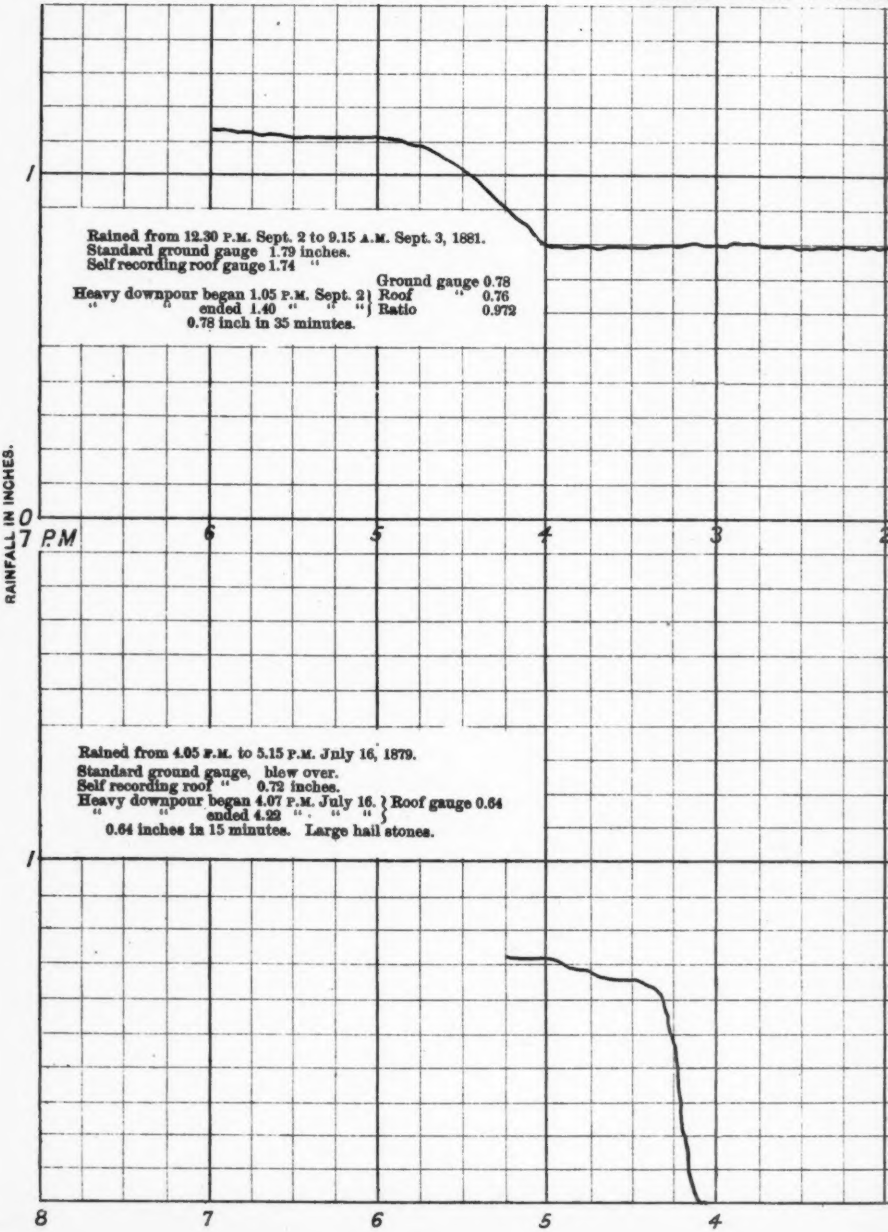
FITZGERALD ON MAXIMUM
RATES OF RAINFALL.




RAINFALL IN INCHES.
Rained from 12.30 P.M. Sept. 2 to 9.15 A.M. Sept. 3, 1881.
Standard ground gauge 1.79 inches.
Self recording roof gauge 1.74 "
Heavy downpour began 1.05 P.M. Sept. 2
" " ended 1.40 " " "
0.78 inch in 35 minutes.
Ground gauge 0.78
Roof " 0.76
Ratio 0.972
Rained from 4.05 P.M. to 5.15 P.M. July 16, 1879.
Standard ground gauge, blew over.
Self recording roof " 0.72 inches.
Heavy downpour began 4.07 P.M. July 16.
" " ended 4.22 " " "
Roof gauge 0.64
0.64 inches in 15 minutes. Large hail stones.
1
0
7 P.M
6
5
4
3
1
8
7
6
5
4

XIMUM RATES OF RAINFALL—CHESTNUT HILL RESERVOIR—BOSTON WATER WORKS.

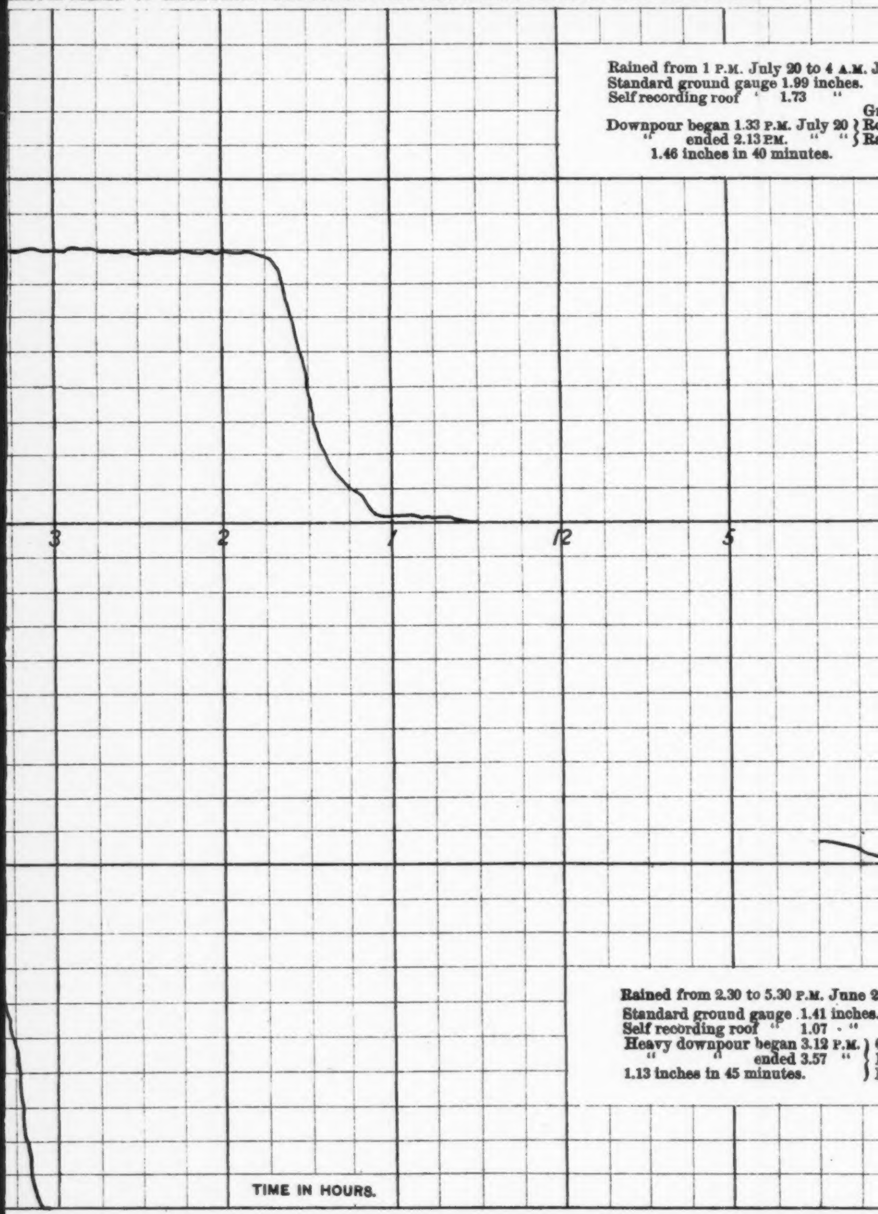
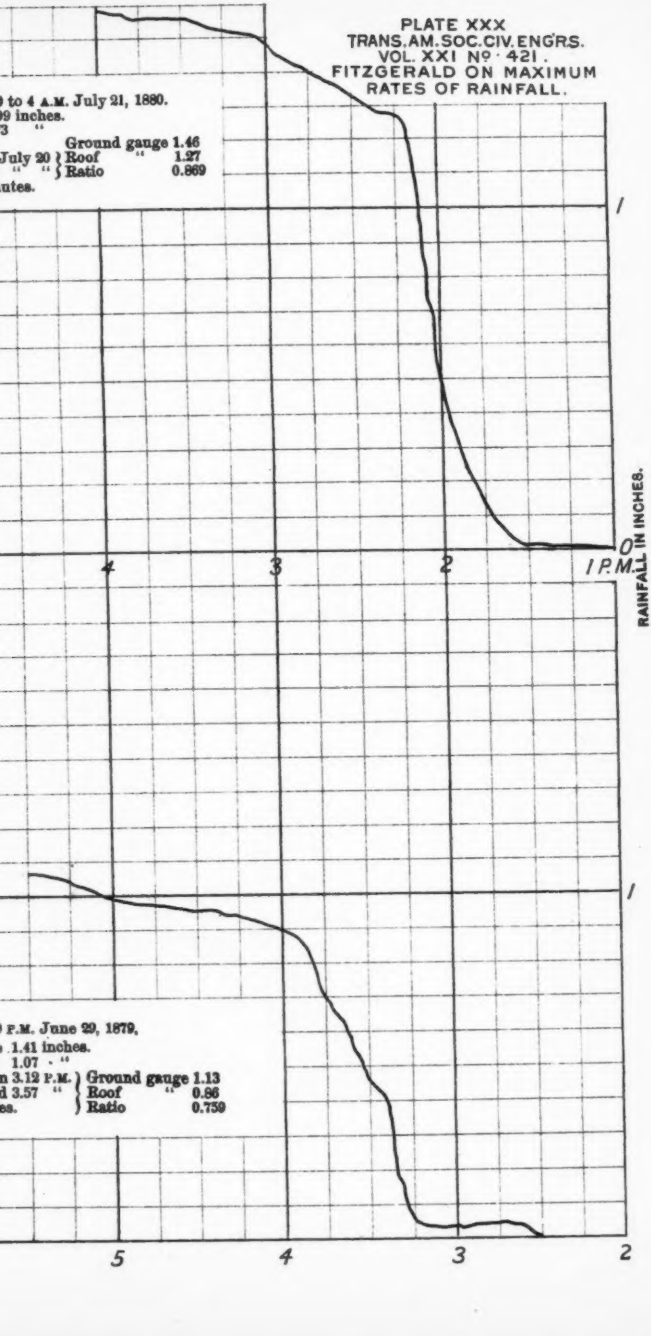
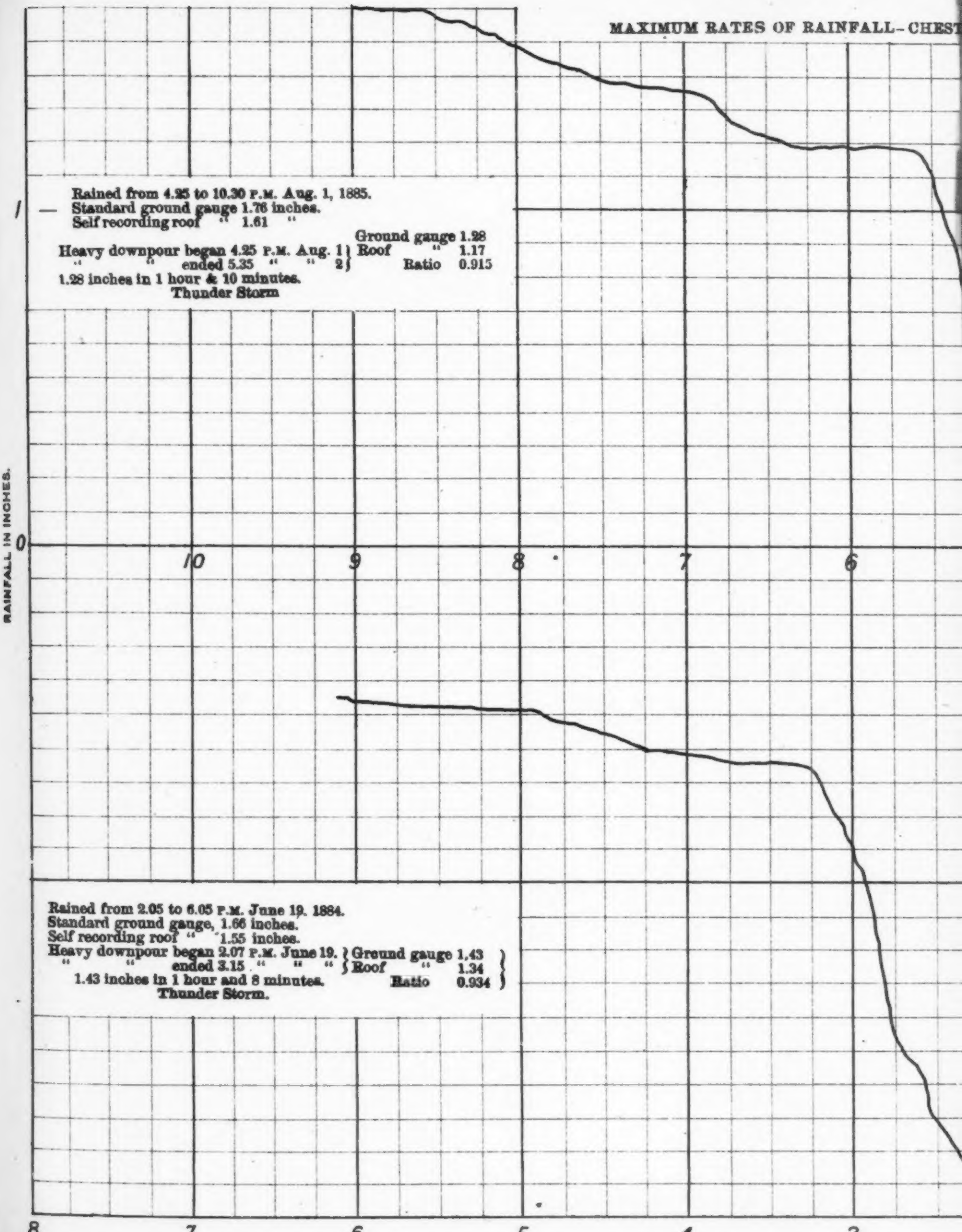


PLATE XXX
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXI No. 421.
FITZGERALD ON MAXIMUM
RATES OF RAINFALL.



Rai
Stan
Self
Hea
"

MAXIMUM RATES OF RAINFALL-CHEST



S OF RAINFALL - CHESTNUT HILL RESERVOIR—BOSTON WATER WORKS.

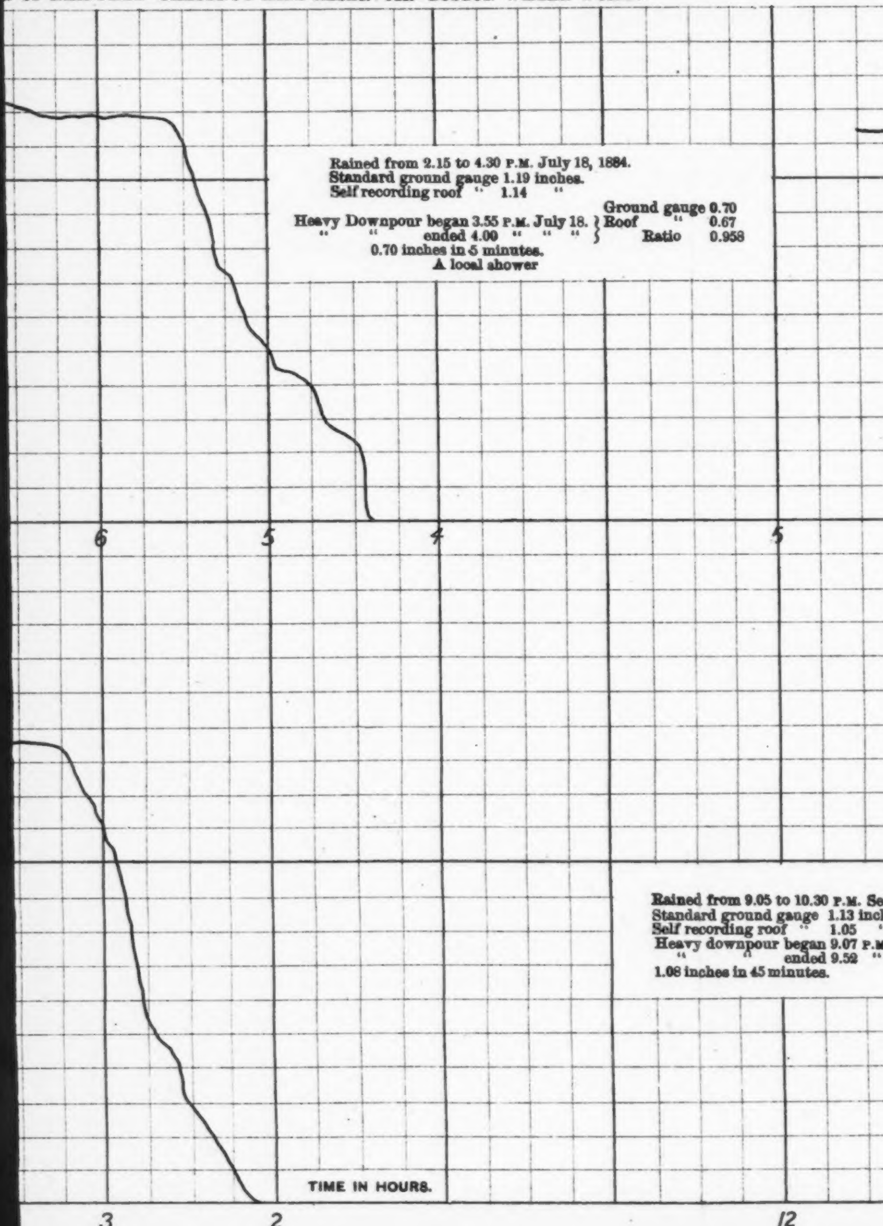
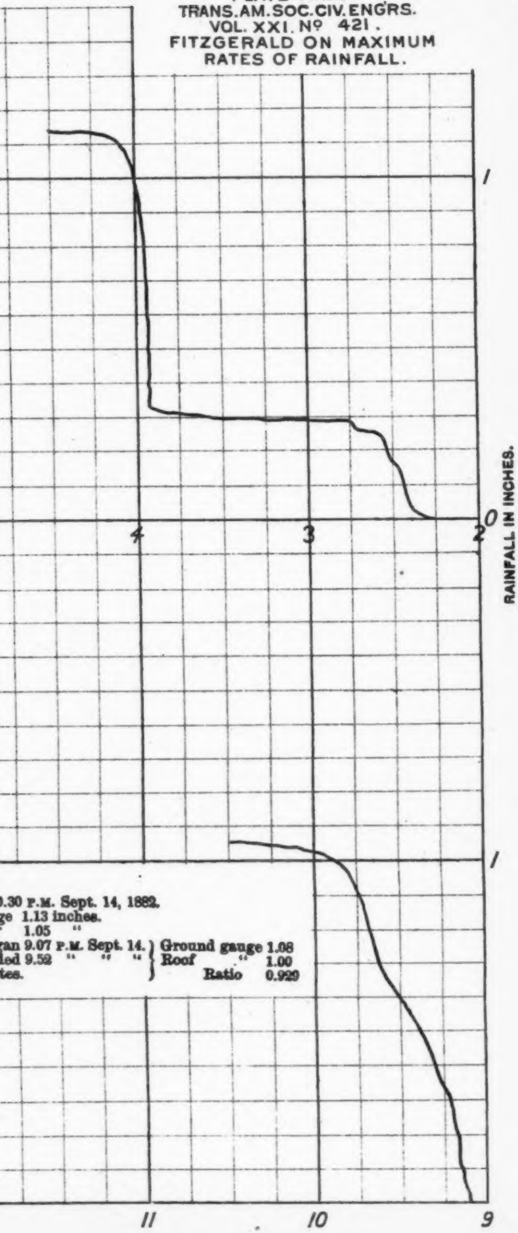
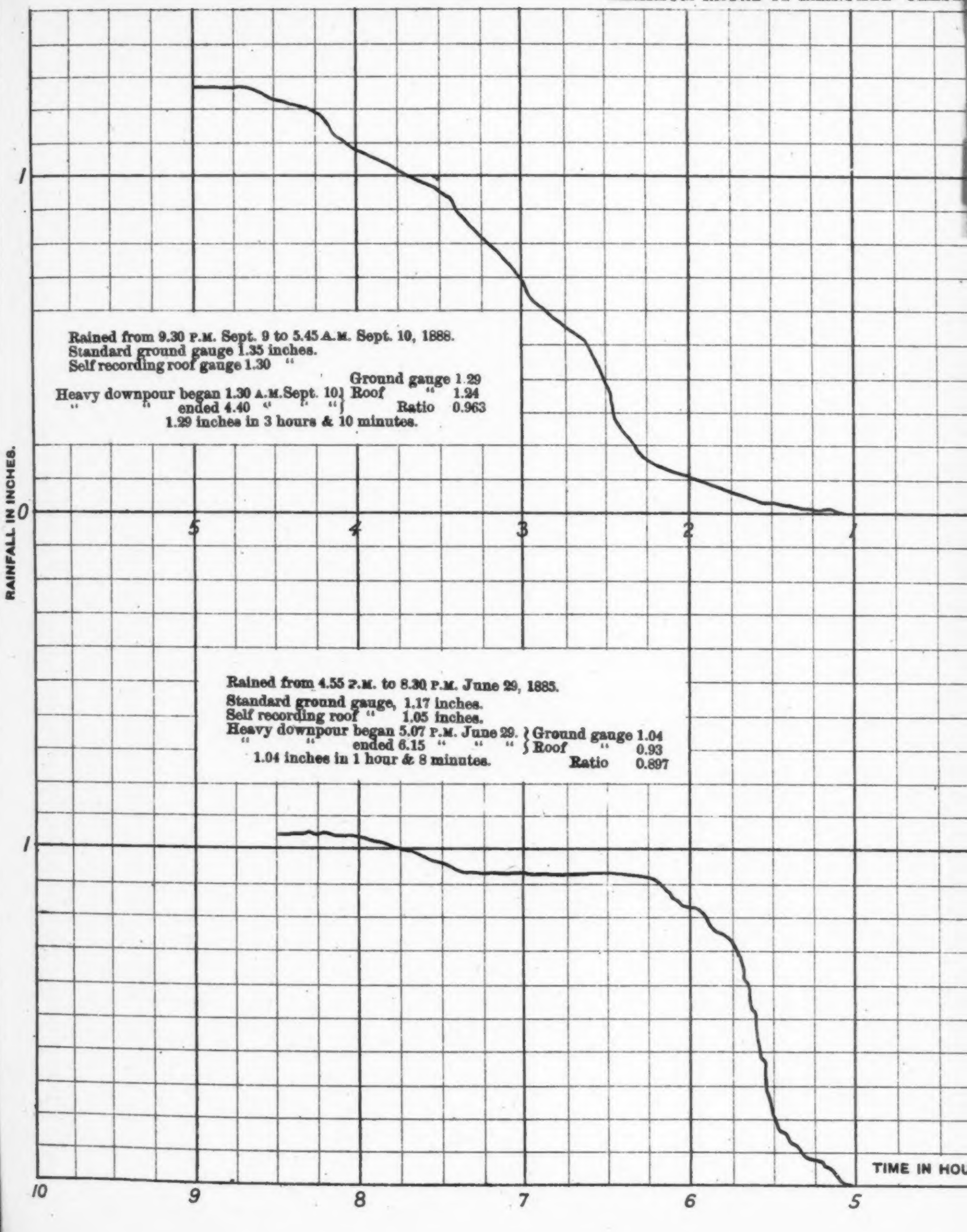


PLATE XXXI
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XXI. Nº 421.
FITZGERALD ON MAXIMUM
RATES OF RAINFALL.




RAINFALL IN INCHES.
1
0
1
10
Ho


RAINFALL IN INCHES.
1
0
5
4
3
2
1
Rained from 9.30 P.M. Sept. 9 to 5.45 A.M. Sept. 10, 1888.
Standard ground gauge 1.35 inches.
Self recording roof gauge 1.30 "
Ground gauge 1.29
Heavy downpour began 1.30 A.M. Sept. 10 } Roof " 1.24
" " ended 4.40 " " " } Ratio 0.963
1.29 inches in 3 hours & 10 minutes.
Rained from 4.55 P.M. to 8.30 P.M. June 29, 1885.
Standard ground gauge, 1.17 inches.
Self recording roof " 1.05 inches.
Heavy downpour began 5.07 P.M. June 29. } Ground gauge 1.04
" " ended 6.15 " " " } Roof " 0.93
1.04 inches in 1 hour & 8 minutes. Ratio 0.897
1
TIME IN HOU
10
9
8
7
6
5

S OF RAINFALL—CHESTNUT HILL RESERVOIR—BOSTON WATER WORKS.

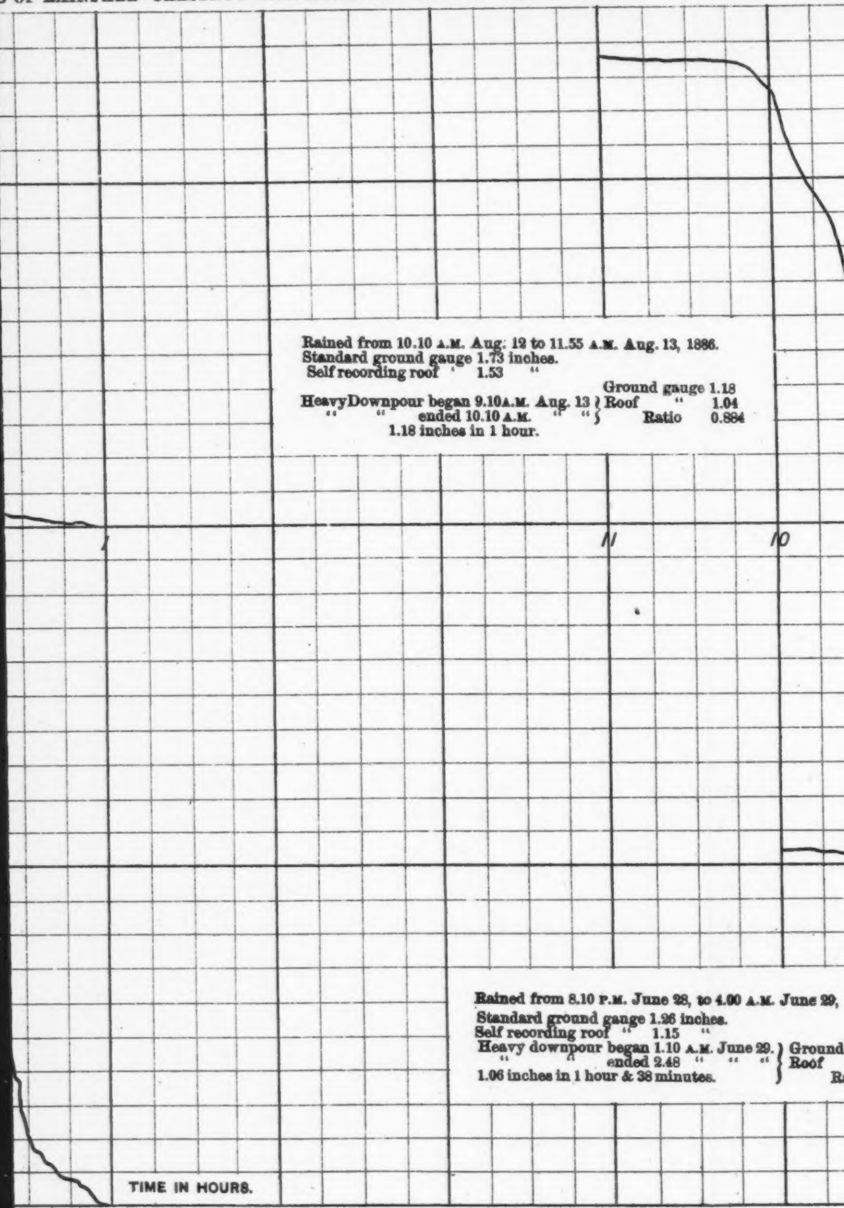
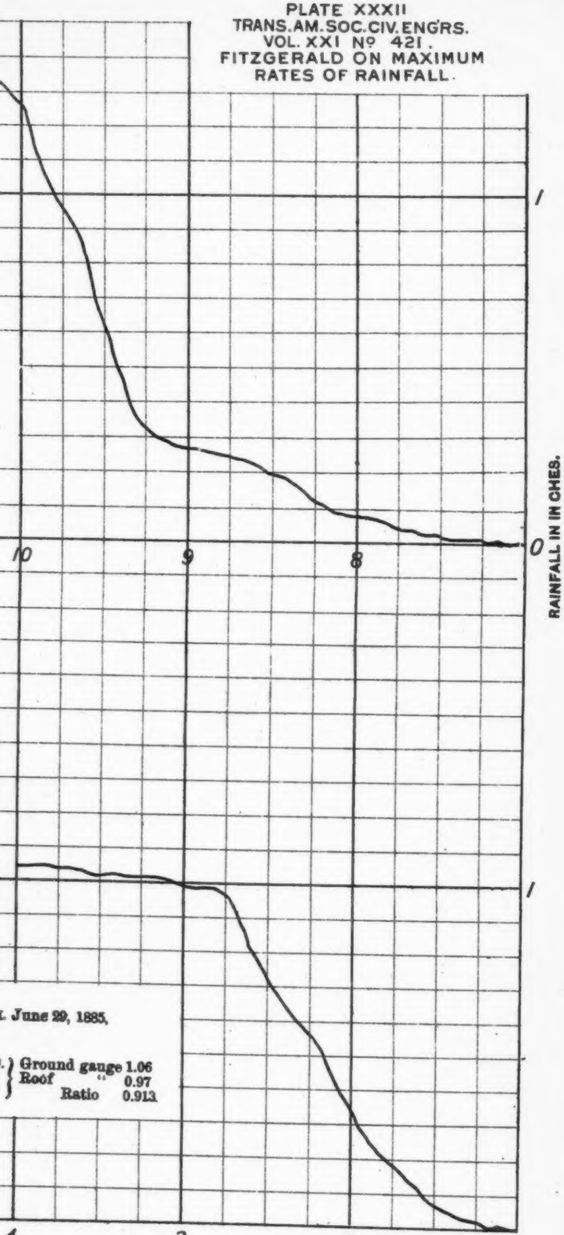
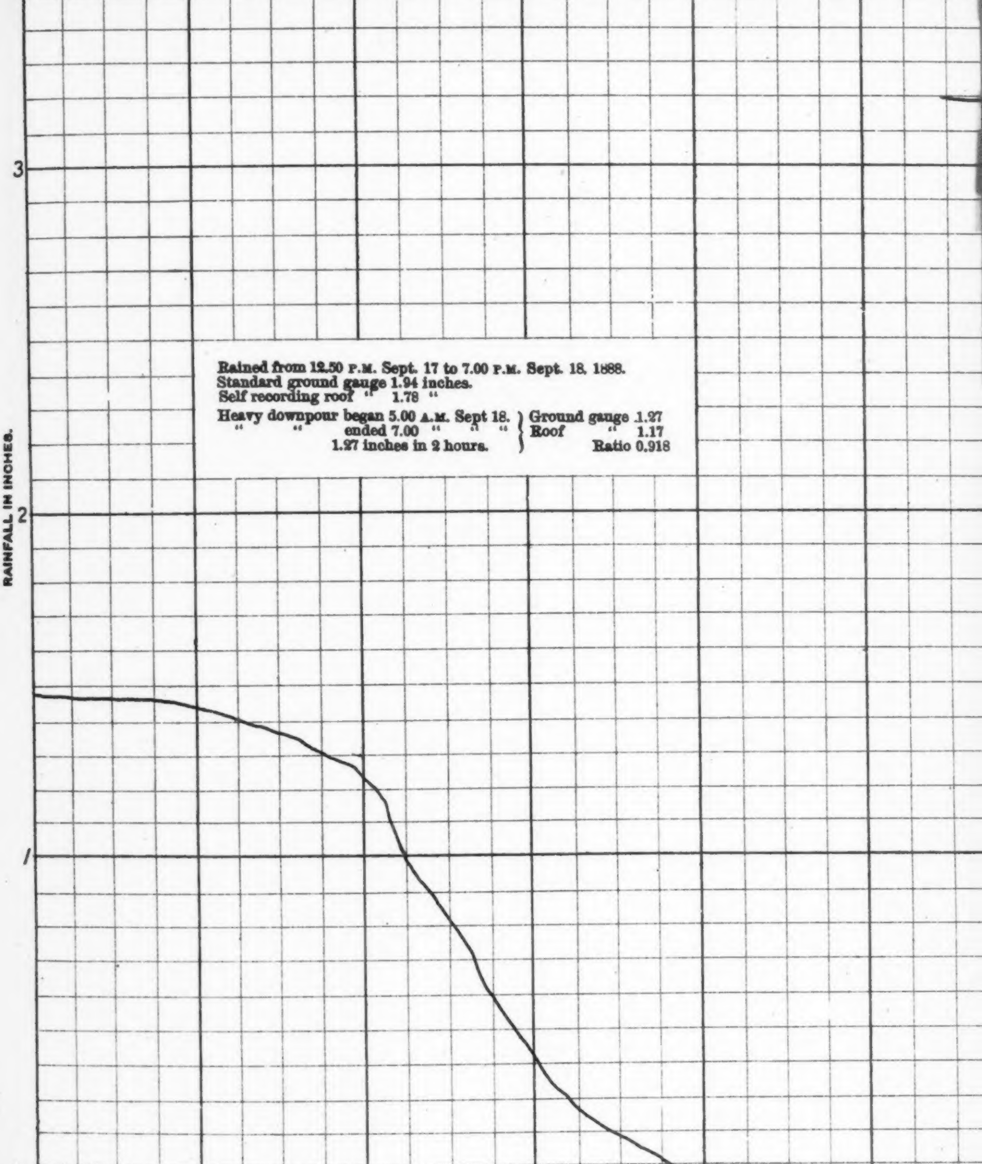


PLATE XXXII
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XXI Nº 421.
FITZGERALD ON MAXIMUM
RATES OF RAINFALL.




RAINFALL IN INCHES.
3
2
1
9

MAXIMUM RATES OF RAINFALL—CHEST



ES OF RAINFALL—CHESTNUT HILL RESERVOIR—BOSTON WATER WORKS.

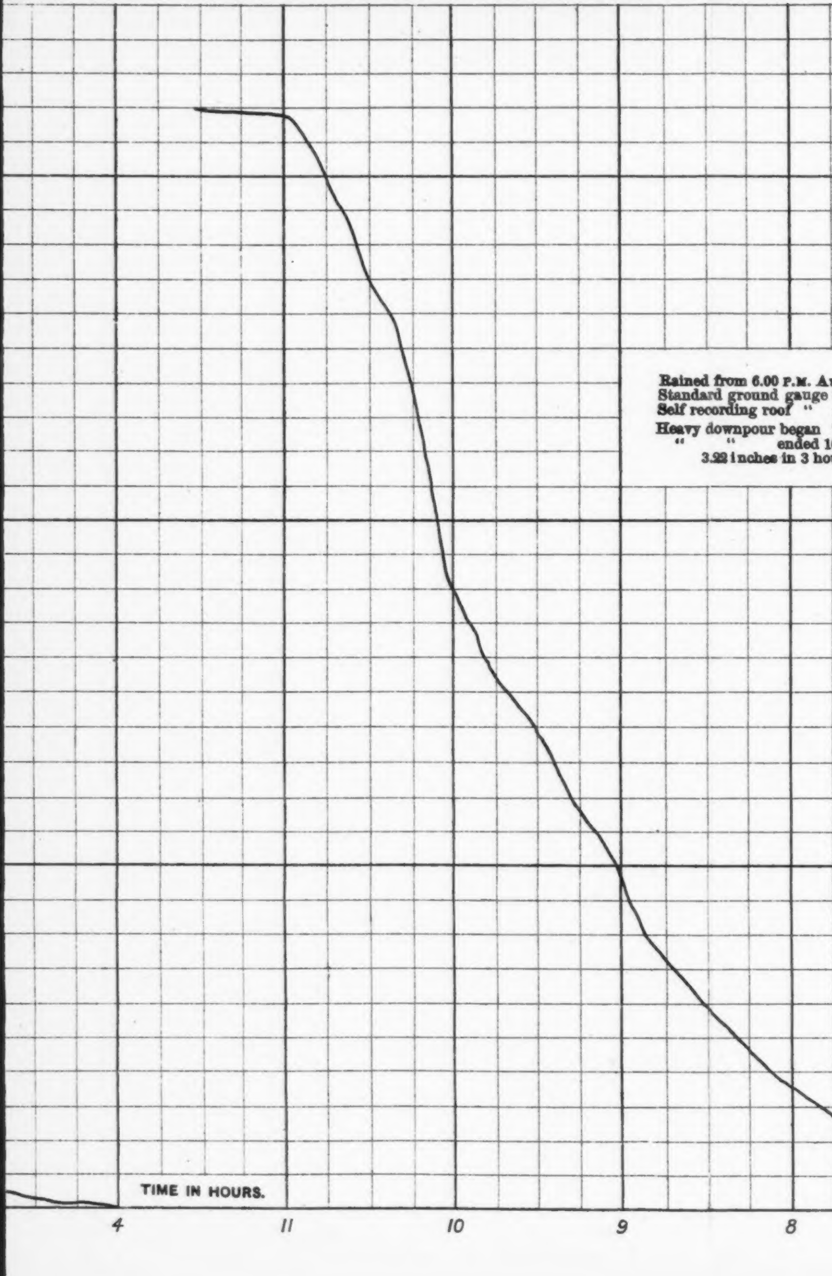
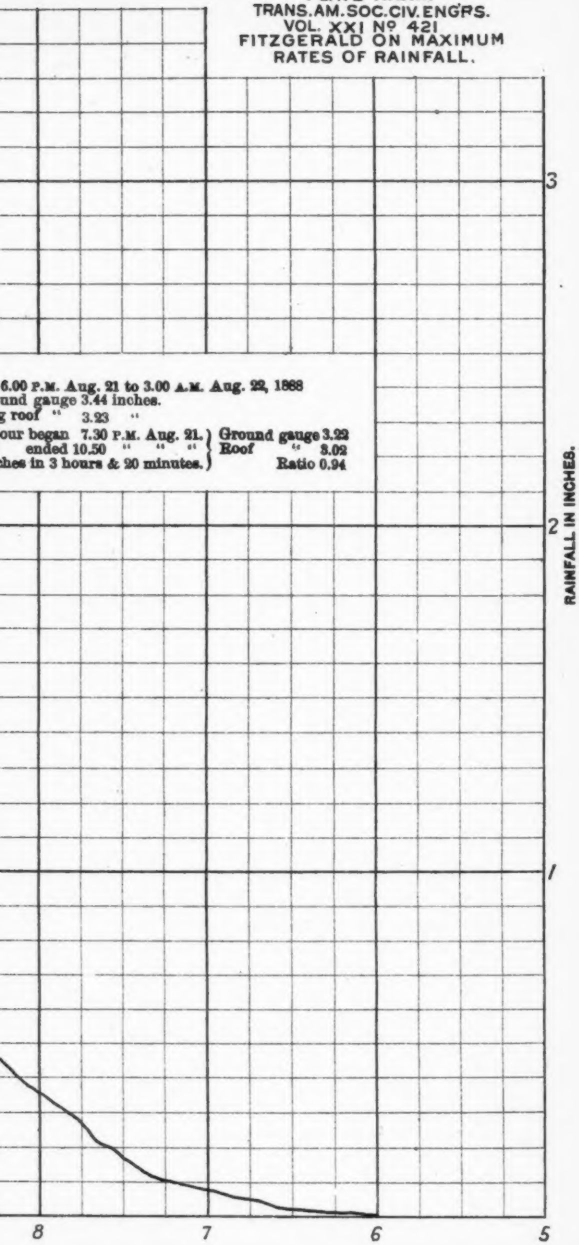


PLATE XXXIII
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXI Nº 421
FITZGERALD ON MAXIMUM
RATES OF RAINFALL.



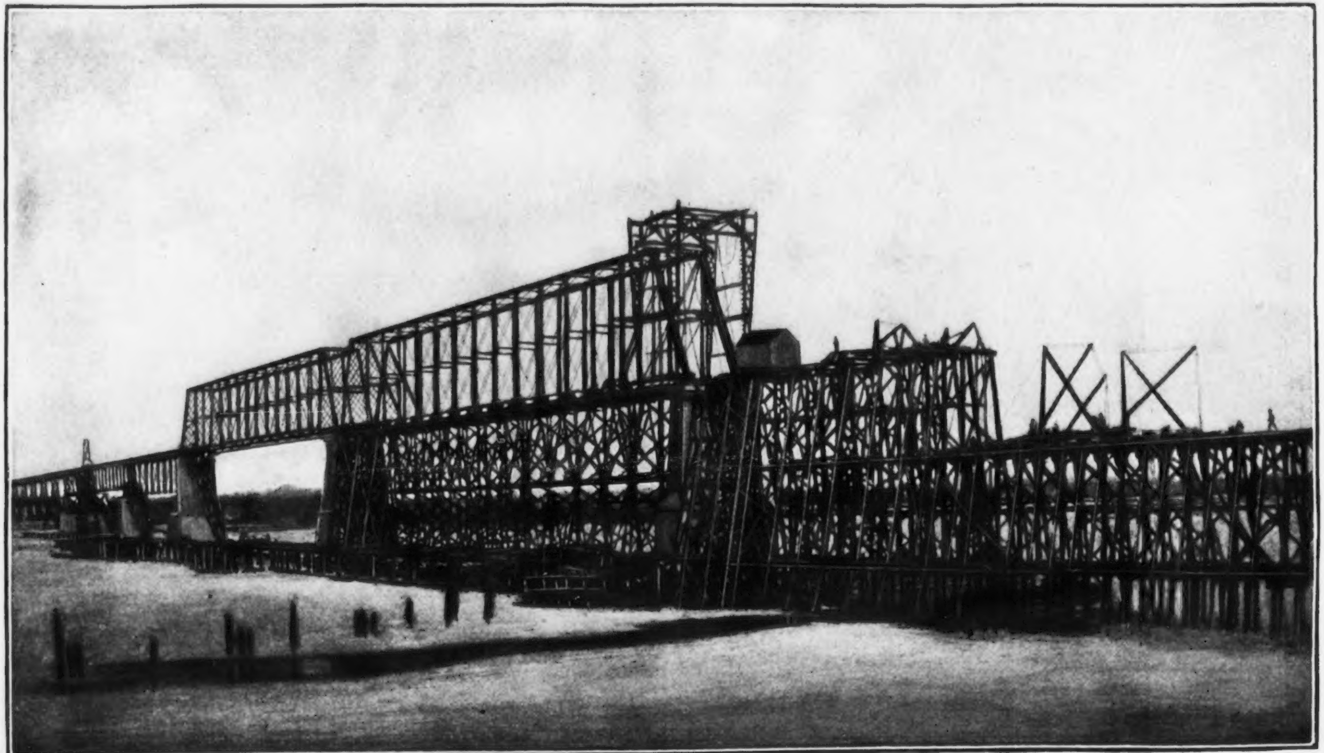


PLATE XXXIV. SIBLEY BRIDGE IN PROGRESS. Vol. XXI, p. 97.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

422.

Vol. XXI.—September, 1889.

THE SIBLEY BRIDGE.

By O. CHANUTE, JOHN F. WALLACE and
W. H. BREITHAUPT, Members Am. Soc. C. E.

INTRODUCTION.

By O. CHANUTE, M. Am. Soc. C. E.

The bridge over the Missouri River at Sibley, Mo., was built under an act of Congress which became a law July 3d, 1884, and which granted to the Kansas City, Topeka and Western Railroad Company, its assigns and successors, the alternative of either building a low bridge, with spans not less than 160 feet in the clear, or a high bridge with spans of not less than 300 feet in the clear, with, in the latter case, the lowest part of the superstructure at least 50 feet above extreme high water mark.

When, in December, 1886, it was decided to extend the Atchison, Topeka and Santa Fé Railroad from Kansas City to Chicago, these rights were transferred to the "Sibley Bridge Company;" Mr. A. A. Robinson,

M. Am. Soc. C. E., was appointed Chief Engineer, and the writer was made Consulting Engineer in charge of the works.

Previous surveys and estimates had contemplated a low bridge; but the more complete surveys, which were begun as soon as it was decided to build the bridge, led to the conviction that it was best to build a high bridge.

It was found that the Channel in the vicinity of the bridge site had shifted some 1 100 feet from 1878 to 1882, and some 700 feet more from 1882 to 1886, with the prospect of still further changes in the near future, so that not only would the low bridge entail a considerable and uncertain expenditure for controlling the channel through the draw-bridge, but it would have been far less favorable for navigation.

It was therefore decided that a high bridge should be built, and the choice lay between two locations.

The upper one was at "Sibley Point" proper, a spur of hills or bluffs jutting out from the general line of the valley, and extending northerly for about half a mile, so as to afford supporting ground for an east and west high bridge line.

The other and lower location was at what is known as the "Sibley Reef," about half a mile below, and involved crossing in a north and south direction, at right angles with the general trend of the valley.

It would have been much preferred to locate the bridge at the upper crossing. Not only was this in the general direction of the road, but it saved nearly a mile in distance and required far less curvature.

The objections to this location were as follows:

First.—It was at the upper end of a "bend" in the river, or rather at the lower end of a "crossing" in which the channel of the river, after impinging against one shore, crosses its bed diagonally, and impinges against the other shore. At such points the channel is proverbially unstable, and changes with the abrasion of the shores, so that a greater number of high through spans, under which boats could pass, would have been required than at the other and more stable location.

Second.—The river was wider at the upper than at the lower location, requiring a bridge 2 550 feet long, as against a bridge 2 000 feet long.

Third.—The bed rock was at greater depth at the upper location; being from 42 to 47 feet below the low water datum, as against 30 to 40 feet at the lower location.

These facts so influenced the cost that the estimates were $1 109 700 for the upper crossing, and $814 950 for the lower or "Sibley Reef" crossing.

The latter was adopted. It derives its name from a reef of boulders which stretches nearly half way across the river, and which abuts on the south or bluff side, upon the remains of a glacial moraine, the only one which the writer knows of above low water in the Missouri River.

The surveys and borings demonstrated the glacial origin of this moraine and reef. The boulders in the bank and in the bed of the river largely consisted of granite, porphyry and metamorphic sandstone, which are not found in their native beds anywhere within three hundred miles of the bridge site. Indeed it is believed that the parent rocks are chiefly found near Lake Superior, and the probabilities are that these boulders drifted down all the way from that region during the glacial period, the site of the bridge being very near the southern line of the glacial drift, as laid down upon geological maps.

Where the bed rock under the river was reached in the pneumatic caissons, it was found striated and streaked with the shallow grooves which are generally considered the marks of glacial action, and all the concurrent circumstances led to the belief that the valley of the Missouri River had been chiefly excavated out of the surrounding bluffs, by the slow and resistless action of a great glacier, bearing upon its upper surface the boulders which had been deposited in the moraine.

The cause of the latter deposit becomes apparent by the inspection of a map of the valley in this vicinity. It is seen that the exact location of the moraine at Sibley Reef was the heel or pivot of a change of direction in the glacier, which thus left a quiet corner in which the boulders in transit were deposited. This is confirmed by the borings, which disclose the fact that the river now flows over the shallowest bed rock to be found between the two bluffs, 4½ miles apart, which bound the valley. Half way between these, under the bottom land, the bed rock was found to be abraded to a depth of 55 and 60 feet below low water, gradually rising thence to the bridge site, where, under the two main piers in the river, it was but 30 feet below the same datum.

The borings showed, moreover, that at the bridge site, the bed rock, instead of being covered with sand, was overlaid with 8 to 10 feet of blue and yellow clays, gradually tapering out toward the north side, thus indicating that after the glacier had ceased its excavating action,

there had been a still pool at this spot, in which the clays had been deposited; their upper surface having subsequently been covered by the boulders, swept down from the glacial moraine by the action of the river, so that it seems certain that the current at this point has never excavated to the bed rock, as so frequently happens during floods at other points in the river.

It will thus be seen that this point offered exceptional conditions of security for the foundations of bridge piers if carried down to bed rock. All anxiety about future undermining might be safely dismissed, and the site being below the bend in the river, it is equally certain that the channel cannot materially change.

The only drawback was that the boulders and clay were likely to increase the cost of pneumatic excavation, but this was practically offset by the shallower depth.

Arrangement of Spans.

Comparative estimates were made of various arrangements of spans, considering the cost of the piers and of the superstructure, and it was found that the best and most economical arrangement was to cover the river, which is here 1 200 feet wide at low water, with three spans of 400 feet each. The following distribution was therefore adopted, the spans and piers numbering from the south or bluff side, toward the north side of the river:

			Feet.
One shore span—deck;	Piers	1 to 2	200
" river " through;	Piers	2 to 3	400
" " " "	"	3 to 4	400
" " " "	"	4 to 5	400
" sand bar span—deck;	"	5 to 6	250
" " " "	"	6 to 7	175
" " " "	"	7 to 8	175
Total			2 000

In addition to which an iron viaduct was built over the bottom lands, 1 900 feet long, in spans alternately 60 and 30 feet, resting upon masonry pedestal piers, and there was added also a temporary wooden trestle, resting upon piles and 3 600 feet long, which is to be filled in hereafter.

The flood marks of 1844 and 1881 were pointed out by local residents upon an old half ruined brick house, about a mile above the bridge site. These proved to be several feet higher than other marks

adopted by the United States Engineers at points both above and below; but as it was thought best to adopt the highest water marks, as understood at the point of location, the bottom chord of the through spans was placed 50 feet above the high-water mark of 1844.

It will be noted from the foregoing description that there are thus but two piers exposed to the full force of the current in the bed of the river at low water. These are placed parallel with the current, the bridge line being at right angles thereto.

Upon the completion of the surveys and final location, plans were duly submitted to the Secretary of War, and his approval was obtained in the spring of 1887.

Character of Foundations.

The bed rock in the Missouri River has generally been found to slope rapidly from one side to the other. It is generally found abraded to a depth of 20 to 30 feet below low water near one bank, and sloping to a depth of 70 to 100 feet near the other. At "Sibley Reef," however, in consequence of the formation which has already been described, and of the considerable width of the valley at this point, it was found practically level under the present site of the low-water river, and thence sloping north gradually for 3½ miles to a depth of 60 feet below low water. Thence it rose again for about 1 mile to the bluffs which form the northerly boundary of the valley. A line of borings across the bottom lands disclosed the fact that the greatest abrading action of the glacier had occurred towards the northern side of the valley, the one furthest away from the bridge site.

At the latter point the bed rock was found at a depth of 30 feet below low water, under Pier No. 2, on the south bank of the river at low water. Thence it ran practically level for 1 200 feet to the north bank of the river, under Pier No. 5, at which it was 31.5 feet below low water. Beyond this it dipped 9 feet in 425, under the sand bar, to the site of Pier No. 7, which was the furthest northerly that it was deemed best to carry down to the rock, and thence the bed rock continued dipping under the bottom lands.

Across the river the bed rock was found covered—first, with a thin stratum of fine sand or gravel not more than 2 feet thick. Above this there lay beds of yellow and blue clays, gradually tapering from the south to the north side, and covered with the boulders which had been

whirled down from the glacial moraine, and these boulders tapered from a thickness of some 20 feet at Pier No. 2, to a thickness of 7 or 8 feet at Pier No. 5, thus acting practically as a continuous bed of rip-rap around the river piers. Above this again there lay at low water the ordinary sand and silt of the Missouri River, which, as is well known, is frequently swept away at high water.

In order that no question should ever arise concerning the stability of the foundations, it was decided to carry down to bed rock, by the pneumatic method, the two piers in the bed of the river, and three out of the four across the sand bar—that is to say, Piers Nos. 3, 4, 5, 6 and 7.

Pier No. 1, or the south abutment, being located well inland, was founded upon the yellow clay or silt composing the bluff. Pier No. 2, at the low-water southerly edge of the river, was founded upon a mass of boulders 20 feet thick, underlaid by blue clay, and Pier No. 8, on the north abutment, was founded upon piles driven in the sand, which is here more or less intermixed with boulders.

The following table exhibits the depths at which each pier is founded, and the character of its foundations:

FOUNDATIONS OF SIBLEY BRIDGE.

Pier Nos.	Height of Pier. Feet.	Depth foundation at low water.	Founded on
1	25.75	+ 34.	Yellow clay and silt.
2	79.	+ 5.	20 feet of boulders underlaid with clay.
3	114.	— 30.	Bed rock.
4	113.4	— 29.4	" "
5	115.5	— 31.5	" "
6	89.22	— 34.6	" "
7	81.85	— 40.5	" "
8	41.22	00	Piles and grillage.

It will be noted from the above that the greatest depth to the bed rock was 40.5 feet, under Pier No. 7 on the sand bar, and that the highest pier above its foundations was Pier No. 5, which is 115.5 feet high.

The weights which these impose on their several foundations will be given in a subsequent table.

DESIGN OF MASONRY.

It was decided to build the piers of "Cotton wood" stone. This is a dolomite which is found on the line of the Atchison, Topeka and Santa

Fé Railroad in Kansas, about 180 miles from the bridge site, and which has been proved in similar works to resist well the effects of the weather and frost.

As a measure of additional safety, Piers Nos. 3 and 4, the two in the main river, were cased in Minnesota granite, from about low water mark to a point 12 feet above, this forming an ice breaker in the shape of a Gothic arch, with the radii diminishing toward the top.

The form and dimensions of these piers at various points will be found on Plate XLII.

The following table exhibits the size of the masonry at top and bottom, the area of the foundations, the estimated weight when loaded with the trains and the resulting pressures :

FOUNDATIONS OF SIBLEY BRIDGE.

Pier No.	Under coping.		Shape of Starling.	Size of foundation.	Area of foundation. Square feet.	Weight in tons.	Tons per square foot.
	Thick.	Length.					
1	6 feet.	24 feet.	None................	33′ 8″ x 15′ 8″	527	764	1.45
2	8	28	Round both ends....	54 x 22	1 188	3 628	3.05
3	9	30	Round and Gothic...	63′ 9″ x 27′ 5″	1 748	6 770	3.87
4	9	30	" " ...	63′ 9″ x 27′ 5″	1 748	6 621	3.78
5	8	28	Round both ends....	43 x 26	1 118	6 041	5.40
6	8	26	None................	42 x 24	1 008	3 466	3.43
7	9	25	"	36 x 18	648	2 478	3.82
8	9	25	"	84 piles.	......	1 071	13 T per pile.

In order to save both weight and expense, Piers Nos. 7 and 8 were carried up but 4 feet above the high-water mark of 1844. Above this they were surmounted with iron towers, which latter carry the deck spans over the sand bar.

The 1 900 feet of iron trestle across the bottom lands is carried on twenty-one iron towers, each resting on four masonry pedestal piers, built of Cotton wood cut stone above the surface of the ground. Below this they are built of concrete, increasing in size by successive steps, so as to give a bearing area upon the soil which shall not exceed a pressure of 1 ton to the square foot. This was deemed judicious because of the light character of the silt composing the bottom lands, and in some instances, where the ground was soft, the areas were extended so as to limit the pressures to ¾ of a ton to the square foot; the foundations being generally carried down from 8 to 10 feet below the surface.

Levels taken since the bridge has been opened to traffic show that these pedestal piers have settled very uniformly, by the compression of the soil from $\frac{3}{8}$ to $\frac{3}{4}$ of an inch, except at two points, where the settlement has been $1\frac{3}{8}$ inches and $2\frac{1}{2}$ inches, respectively. This will be rectified by the insertion of iron shimming plates, under the iron legs of the towers resting upon the masonry and carrying the alternate 30 and 60 feet iron plate girders of the superstructure.

Construction.

As soon as the location was decided upon, and the surveys had sufficiently progressed, a contract was entered into (January 10th, 1887) with the firm of Sooysmith & Co., to put in the foundations and to build the masonry, at an agreed schedule of prices. This firm was at that time completing the substructure and masonry for a similar bridge at Randolph, some 20 miles above Sibley, and as fast as practicable it transferred its plant and forces to the latter point.

This contract proved thoroughly satisfactory. The work was carried through in a less period of time than at any bridge heretofore built across the Missouri River, and it was thoroughly well done. The foundations were made perfect, the masonry was very good, and the job was satisfactory in every respect.

As there were over 30 000 tons of materials to be received (timber, stone, cement, iron, etc.) for the foundations, masonry and superstructure, the first requirement was to obtain, if possible, a connection by rail with the bridge site. The Wabash Railway passed within 3 miles, and an arrangement having been made with that company, second-hand rails and ties were procured from the Atchison, Topeka and Sante Fé Railroad, with which a service track was laid about 3 miles long, from the Wabash Railway to Sibley Bridge site, together with about a mile of the necessary sidings. This was operated by a light locomotive which the contractors procured, and being completed in February, the accumulation of material began.

On March 23d, 1887, ground was broken at the bridge site, by commencing excavation for the pile foundations of Pier No. 8, or the present north abutment.

From this time forward the work was prosecuted vigorously; but as the operations were begun in the spring of the year, when two floods were to be encountered, that of April from the breaking up of the upper

river, and that of June from the melted snows in the mountains, it was not practicable to begin first upon the two river piers (3 and 4), as would have been desired, and the first pneumatic foundations were accordingly put in on the sand bar.

The following condensed table shows the dates of beginning the excavation at each pier, of the completion of the foundation proper, of the beginning of laying the masonry after the foundation was completed, and of the finishing of the pier.

SCHEDULE OF SUBSTRUCTURE WORK—SIBLEY BRIDGE.

Foundation.	Character.	Sinking Begun.	Foundation Completed.	Masonry Begun.	Pier Completed.
8.	Piles.	March 23d, 1887.	May 10th, 1887.	May 13th, 1887.	July 8th, 1887.
7.	Pneumatic.	April 22d, "	Aug. 2d, "	Aug. 5th, "	Aug. 11th, "
6.	"	May 7th, "	Aug. 22d, "	Aug 22d, "	Sept. 8th, "
5.	"	June 7th, "	Aug. 25th, "	Sept. 21st, "	Oct. 13th, "
4.	"	Aug. 27th, "	Oct. 29th, "	Oct. 30th, "	Nov. 18th, "
3.	"	Aug. 27th, "	Nov. 22d, "	Nov. 22d, "	Dec. 15th, "
2.	Excavation.	Aug. 6th, "	Aug. 17th, "	Sept. 21st, "	Oct. 21st, "
1.	"	June 8th, "	June 20th, "	July 14th, "	July 28th, "
Pedestals.	"	April 14th, "	July 27th, "	June 6th, "	Sept. 1st, "

Meanwhile proposals had been received from various bridge works for the superstructure, and the contract having been awarded to the Edgemoor Iron Company on the 15th of January, 1887, the plans were made, the materials ordered and rigidly inspected, and the manufacture of the parts began at the shops in June, the iron viaduct being first taken in hand.

The following table shows the dates of erection at the bridge site of the several spans:

SCHEDULE OF ERECTION OF SUPERSTRUCTURE—SIBLEY BRIDGE.

Between Piers.	Span.	Date Begun.	Date Completed.
Iron Viaduct.	60 and 30 feet.	July 25th, 1887.	Sept. 10th, 1887.
7 to 8	175 feet deck.	Sept. 13th, "	Sept. 24th, "
6 " 7	175 "	Sept. 30th, "	Oct. 10th, "
5 " 6	250 "	Oct. 13th, "	Oct. 30th, "
4 " 5	400 feet through.	Nov. 24th, "	Dec. 15th, "
3 " 4	400 "	Dec. 24th, "	Jan. 19th, 1888.
2 " 3	400 "	Jan. 28th, 1888.	Feb. 11th, "
1 " 2	200 feet deck.	Nov. 22d, 1887.	Dec. 12th, 1887.

While the writer was in general charge of the works, and visited them frequently, the more immediate charge of the substructure and erection was placed in the hands of Mr. John F. Wallace, M. Am. Soc. C. E., who was appointed Resident Engineer.

The supervision of the plans, and inspection of the materials and shop work for the superstructure, was likewise intrusted to Mr. W. H. Breithaupt, M. Am. Soc. C. E., who was appointed Assistant Engineer of superstructure.

These two gentlemen having carried through their respective tasks to a successful termination, and completed an important bridge which is thought to reflect credit upon all concerned, they are herewith left to tell how they did it, by continuing this narrative.

CONSTRUCTION.

By John F. Wallace, M. Am. Soc. C. E.

On March 14th, 1887, the writer was placed in charge of the construction of the Sibley Bridge as Resident Engineer. Prior to this date the location and general plan had been determined upon by O. Chanute, M. Am. Soc. C. E., Consulting Engineer, and approved by A. A. Robinson, M. Am. Soc. C. E., Chief Engineer. A contract for the substructure had been let to Sooysmith & Co., of New York City; a service track 3 miles long, with the necessary sidings, had been constructed connecting the bridge site with the Wabash Western Railway near Orrick, Missouri; extensive borings, under the immediate direction of Otto Sonne, M. Am. Soc. C. E., had also been made covering the entire vicinity of the bridge site.

During March the various piers were located, base lines were laid out and carefully measured, and the triangulation made connecting the various bases and points upon both sides of the river. Levels were run connecting the various bench-marks of both the railroad and Government surveys and checked on the high-water marks pointed out by the old settlers. The relation between the railroad datum, which was adopted as the bridge datum, the St. Louis Directrix, and the datum of the Missouri River surveys by the United States Engineers (which is mean gulf tide at Biloxi, Miss.) was found to be as follows:

United States datum, mean gulf tide............	0.000
Chicago, Santa Fé and California Railroad datum....................................	135.613
The St. Louis Directrix........................	413.300

In reference to the railroad datum, low water was assumed to be 550.000, being 685.613 feet above the sea level. High water of 1881 was found to be at an elevation of 580.300. High water of 1844 was found to be at an elevation of 587.400. The lowest part of the iron work was calculated to be placed at an elevation of 637.400, giving a clear headroom for navigation of 50 feet between extreme high water and the bottom chord of the bridge, the fluctuation between high and low water being 37.400. The elevation of the base of the rail was calculated to be 642.500, 92.5 feet above low-water mark. On account of transportation facilities it was decided to conduct the work from the sand bar on the north side of the river, and to construct the viaduct foundations and

the foundations of the piers situated upon the sand bar first, leaving the construction of the main piers located in the river proper until after the subsidence of the spring floods. Work was, therefore, commenced at the site of Pier 8, on the 23d day of March, 1887, by excavating the surface material down to a level with the stage of the water in the river. In this excavation a coffer-dam was constructed and completed April 8th. This coffer-dam was sunk to a depth of 20 feet below the level of the sand bar, and the inclosed sand removed by a centrifugal pump. Inside of the coffer-dam eighty-four white oak piles 50 feet long were driven. The piles were cut off below low-water mark. These piles penetrated a stratum of boulders and clay at a mean depth of 20 feet below low water. The final penetration of these piles did not in any case exceed 1 inch during the last ten blows of a 3 200-pound hammer falling 25 feet. The pile driver was operated by a double drum Mundy hoisting engine. Pile driving was completed May 10th, the work being slow and tedious on account of the length of the piles and the hardness of the material into which they were driven. On May 13th the grillage was constructed on the piling and the laying of masonry commenced. The masonry was completed to the coping by May 25th, the coping was added July 8th, finishing the pier.

The foundations of Piers Nos. 7, 6, 5, 4 and 3 were constructed by the pneumatic process in the order named.

Pier No. 7.

The caisson for the foundation of Pier No. 7 was constructed in place and sinking commenced April 22d, 1888, with the cutting edge at an elevation of 560.000. The sinking progressed rapidly through sand until May 5th, when at an elevation of 536.0 boulders were encountered, which became very numerous and compact as the sinking progressed. At an elevation of 518.0 a ledge of limestone rock 2 feet thick, covering about one-fifth of the area of the bottom of the caisson, was encountered, which required blasting for its removal. Bed rock was finally reached August 2d and the masonry on the pier completed August 11th.

Pier No. 6.

The caisson for this pier was also constructed in place; sinking commenced May 7th, and was completed August 22d. The character of the material through which this caisson passed was sand, boulders and

clay in the order named. The cutting edge was sunk to an elevation of 515.4; the masonry on the pier was completed September 8th. The details of this pier are shown on Plate XLI.

Pier No. 5.

The caisson for this pier was constructed on the shore $\frac{1}{2}$ mile above the bridge site, and on May 3d was launched and floated into approximate position between mooring piles which had previously been driven to assist in placing the caisson. As soon as the caisson was anchored to the piling, a sand bar commenced to form below and on the in-shore side, which caused so much trouble in bringing the caisson into proper position that five days intervened before the exact position was obtained. This was accomplished by keeping a heavy strain upon the mooring lines leading in the desired direction, and, at the same time, jetting around the edge of the caisson. In order that the caisson might be as light a draught as possible, only one course of roofing was placed upon it until after it was placed in final position, after which the seven remaining courses of decking were constructed. The sinking commenced upon June 7th and continued until August 18th, at which date the caisson landed upon the bed rock at an elevation of 518.5. Under this pier the bed rock sloped 3 feet in the length of the foundation. The high portion of the ledge was removed by blasting until a uniform bearing was obtained and the foundation firmly secured. By August 25th the air chamber and shafts were filled with concrete and the laying of masonry under way upon the pier above. During the sinking only as much masonry was laid in position as was needed to provide weight for sinking the foundation and to keep the work above the surface of the water. The material through which the caisson passed in sinking consisted of a conglomerate mass of sand, gravel, boulders and clay, which became very hard and compact near the bed rock. While in sinking the foundations of Piers Nos. 6 and 7 much of the material, consisting of sand and silt, was removed through the blow-out pipes by the air pressure. Most of the excavation for this foundation was loosened by pick and hoisted through the air lock in the excavating shaft. The manner of operating the excavator, and the drawings for the same, are shown by the details on Plate XL, which also shows the general plan of caisson used. The size and details, however, on the drawings are of Caisson No. 6. Pier No. 5 was completed October 13th.

Pier No. 4.

Owing to the high stage of the June flood and its prolonged duration, it was not deemed expedient to place the caissons for Piers Nos. 3 and 4 in position in the stream until the waters commenced to subside during August. The caissons had, however, in the meantime been constructed and were in readiness to launch when the proper time arrived. The caisson for Pier 4 was launched August 9th and was floated into position and secured between the mooring piles without incident. Afterward seven courses of decking were added and 9 feet of crib work filled with concrete constructed upon the top of the caisson. Sinking commenced August 27th and continued until October 23d, on which date the cutting edge of the caisson was landed securely upon bed rock at an elevation of 520.0. In sinking Caisson 4, boulders were encountered in the sand, at once followed by several strata of hard, compact clays, which continued within a short distance of bed rock, when a shallow stratum of gravel was encountered immediately upon the rock. It was found necessary to remove fully 90 per cent. of the material excavated in sinking this foundation through the excavating lock, which rendered the sinking slow, tedious and expensive. On October 29th, the working chamber having been filled with concrete, the air was cut off, and the laying of masonry was pushed forward upon the pier, which was completed November 18th.

Pier No. 3.

The caisson for Pier No. 3 was launched August 24th. Prior to launching Caissons 3, 4 and 5, false bottoms were constructed over the lower part of the working chambers to render them light of draught. After securing the caissons in position, and filling the chambers with compressed air, these bottoms were broken up and the material out of which they were constructed was shoved out under the cutting edge. In launching Caisson 3, the false bottom was broken by contact with a snag, and, as the water was not deep enough to float the structure, it grounded in some 8 feet of water. One of the barges containing an air compressor was at once brought alongside and the caisson raised by pumping air into the working chamber. The steamer "Park Bluff" then took the caisson and compressor barge in tow and dropped down the stream toward the bridge site. The current at "Sibley Reef," at the stage of water then existing, ran so fiercely that the steamer was not able to hold the

fleet in tow, and when the future position of the caisson was approached, stone anchors were cast, and by their help the caisson was swung into position between the mooring piles, and then allowed to settle upon the river bed. The bottom of the river at this point was covered with boulders from 1 to 9 feet in diameter. The caisson rested upon the boulders in such a manner that the lower right hand corner was some 5 feet lower than the upper left hand corner, and after the false bottom was removed, a channel some 9 feet deep and 30 feet wide was found to exist, running diagonally across under the caisson, which was upheld by boulders of various sizes under different parts of the cutting edge. Owing to the peculiar position of the caisson and the fierceness of the current, the water inside of the working chamber dashed to the roof, and rendered all work in the chamber slow, difficult and dangerous. But few workmen could be induced to enter the chamber, and these were compelled to use life lines, which were attached to the body of one workman and held by two of his fellows clinging to the interior bracing of the chamber. The compressed air would, of course, only keep the water down level with the highest corner of the chamber, even with the water calm and no current existing. It was necessary to level the caisson and to secure a bearing for the cutting edge before the air pressure could be relied upon to clear the chamber of water and enable the work to be pushed with force. The work of blasting the boulders and distributing the fragments over the bottom of the chamber continued day and night. Sand bags were also cast into the river on the upper side of the caisson, and were carried through to the lower side of the chamber by the current and assisted in stopping the channel under the caisson. After twenty-one days and nights of continuous effort, the cutting edge was finally embedded in the boulders and the full complement of pressure men induced to enter the working chamber. The average elevation of the top of the boulder bed was 548.0. At 535.0, after passing through a compact mass of boulders and gravel, a stiff blue clay was encountered which was free from gravel and sand and picked apart in large dry flakes. At 529.0 the blue clay gave place to a tough yellow clay, very hard and stiff, which was so difficult to pick that blasting was rendered necessary to loosen it. At 525 a stratum of gravel and sand was found, which continued to the bed rock, which was reached at an elevation of 520.0 on November 13th. After filling the working chamber and the different shafts with concrete, the laying of masonry on the pier was

resumed, and finally completed December 15th, 1887. The masonry on the pier was laid during freezing weather. Warm brine containing eight per cent. of salt and the best Louisville cement was used in the mortar. Subsequent examinations have shown the mortar in this pier to be equal in quality to that used during weather of a higher temperature. The completion of Pier No. 3 finished the substructure, as the construction of the shore Piers Nos. 2 and 1, resting upon beds of concrete 8 feet in thickness, had been carried forward and completed during the progress of the work on the other piers. The eighty-four foundations for the viaduct towers had also in the meantime been completed. These foundations consisted of stone piers from 8 to 12 feet in height, resting on beds of concrete 8 feet in thickness, which were so proportioned that the weight on the soil beneath should not exceed 1 ton to the square foot.

The following quantities of material were used in the substructure:

Piling, 3 360 lineal feet.
Timber in caissons and cribs, 1 070 636 feet B.M.
Iron in caissons and cribs, 127 776 pounds.
Concrete in air chambers, 1 625 cubic yards.
Concrete in cribs and foundations, 4 174 cubic yards.
Limestone masonry, 7 094 cubic yards.
Granite masonry, 313 cubic yards.
Limestone coping, 416 cubic yards.
Granite bridge seats, 38 cubic yards.
Viaduct foundations, 670 cubic yards.
Total masonry, 8 521 cubic yards.
Riprap, 4 200 cubic yards.
Displacement of caissons, 234 417 cubic feet.
Boulders excavated from caissons, 78 788 cubic feet.
Excavation for dry foundations, 4 814 cubic yards.

Cement.

The following amount of cement of different manufacture was used in the construction of the substructure :

Portland cement	500	barrels.
Milwaukee "	100	"
Utica "	1 468	"
Kansas City "	4 440	"
Louisville "	3 506	"
Total	10 014	"

The Portland cement was used in sealing the air chambers and in pointing. The Louisville cements were used in laying the masonry.

The Kansas City and Utica cements were used, mainly, in foundation and concrete work. All cement used was first stored upon arrival in a cement house and was carefully tested before being permitted to enter the work. During the season seventeen car loads of cement were rejected out of the total amount received.

WATER RECORDS.

Owing to the work being conducted from the sand bar on the north side of the river, and to the constant fluctuation for which the Missouri River is noted, it was necessary to provide some system by which we could be duly warned of the approach of flood waves. The records of the various water gauges on the Missouri River from Kansas City to Sioux City were diagramed, in order that we might have a graphical presentation of the previous flood waves. Daily telegraphic reports were received from Sioux City, Omaha, Plattsmouth and Kansas City, and were recorded upon this diagram. After the first flood we were able to determine the approach and probable height of the rise of the water during the succeeding forty-eight hours. Under the peculiar circumstances existing at Sibley Reef, the information derived from these reports and this diagram was of great assistance in the prosecution of the work.

ERECTION.

On July 5th, 1889, the first car load of material for the superstructure arrived at the bridge site, and on July 25th the first tower for the viaduct was raised. The viaduct was erected by means of a traveler, which "straddled" the entire structure on legs resting on wheels that ran on rails located upon each side and outside of the two lines of foundation piers. Between the two lines of piers a standard gauge track was laid connecting with the material yard tracks; upon this track under the viaduct the cars containing the material for the superstructure were placed. The material was then lifted directly into place by the traveler without further handling. This "straddler" was also used to erect the three deck spans between Piers Nos. 5 and 8. The last girder for the viaduct was hoisted into place September 10th. The progress table on page 105 gives the dates of the erection of the various spans. The long spans over the low water river were erected from false works resting upon piling driven into the river bed by the use of an ordinary traveler. The character of the river bed at "Sibley Reef"

enabled us to drive piling for this false work without fear of scour, but the erection not being completed by the time the ice began to run in the river, we experienced considerable trouble by the ice cutting the piling and the work was in constant danger from moving ice during the erection of the three 400-foot spans. Up to the 19th of December, although the weather was cold, yet it did not prevent the vigorous prosecution of the work. On that date a "blizzard" bore down upon the works from the northwest, and for four weeks storm followed storm in rapid succession, covering the false work and lines with ice and snow, the thermometer at times falling as low as 25 degrees below zero. The work was continued and completed during this weather, as it was feared that as soon as the weather moderated the ice would move out of the river, carrying away our false work and as much of the spans as might be in course of erection at the time. During this period two of the workmen lost their lives by falling from the false work and one by slipping from the ice into the river.

In order to open up the Chicago, Santa Fé and California Railroad for traffic, the false work between Piers Nos. 2 and 3 was erected strong enough to bear up trains and also the span in course of erection, and on the 26th of January the first train was permitted to cross the bridge, and this span was subsequently erected without interfering with the operation of the railroad. On February 11th, 1888, the last end pin was driven and the bridge substantially completed. Fortunately the ice in the Missouri River did not move until after this, to us, very important event, but the day following the ice moved out of the river.

Rectification Works.

In bridging the Missouri River, a very important matter to consider is the proper means to adopt to retain the river under the bridge proper and to prevent the structure from being flanked by the turbulent stream. The valley of the Missouri is generally from 4 to 6 miles wide, and the bed rock from 30 to 80 feet deep below the top of the alluvial deposit. This alluvial deposit consists generally of a very fine silt, but beds of clay and black soil are occasionally found. The stream itself swings from side to side of the valley like a mighty serpent, until it strikes the limestone bluffs which bound it. During and succeeding the spring floods the concave bends are continually cutting and the bars on the convex side of the river continually increasing. The banks

are generally from 25 to 30 feet above the low water river, and are covered with from 1 to 3 feet of black soil washed into the valley by the tributary streams. This land is thickly settled and covered with beautiful farms, which, in the convex bends, are to a greater or less extent yearly sacrificed to the river. The greatest amount of cutting occurs during the falling water succeeding a rise, the water running toward the river through the fine silt and continually undermining the banks. Where some points are temporarily held by a deposit of stiff clay, the bank below is rapidly cut out by the fierce action of the eddy that is generated by the water whirling around the point extending into the river, and the clay points are eventually flanked. The progress of the cutting has been known to extend from ½ to ¾ of a mile back in the convex bends in a single season. The expense of controlling the river in the vicinity of the bridges that have been built over the Missouri River has, in one or two cases known to the writer, eventually exceeded the cost of the bridge itself. At Sibley the location of the south end of the bridge is against the bluffs, and the land on that side of the river lying along the bluffs above the bridge is low and uninhabitable. The problem consisted simply in our ability to hold the bank on the north side of the river for a distance of some 4 miles above the bridge site connecting on to rectification works previously constructed by the Wabash Western Railway, and letting any cuttings that might occur on the south side of the river, as the result of our proposed works, take care of themselves. As a first step toward securing the data that would give the necessary information to enable the works at Sibley Bend to be planned and executed in the most economical manner, a careful examination of the different Government Surveys extending over a period of from ten to fifteen years was made.

In the winter of 1887 a careful survey was made of the river in the vicinity of Sibley. In August of 1887 a second survey was made. (Plate XXXVII.) Between these two surveys the river cut back a distance of some 1 200 feet in the bend above the bridge. The survey of January, 1887, showed that the deep-water channel of the river followed close to the north shore line around the entire bend. Owing to the material in the upper part of the bend being softer than that in the lower part, and a clay point existing about ¼ of a mile above Dike "C," the bank in the upper part of the bend cut very rapidly, while little or no cutting occurred below the center of the original bend; this caused the current to

deflect toward the south side of the river, and temporarily protected the bank immediately above the bridge site. It was decided to construct Dike "C," shown on Plate XXXVII, a distance of 700 feet into the river, in the upper part of the lower bend as it existed in August of 1887; it was also decided to construct Dikes 1, 2, 3, 4, 5 and 6 in the lower part of the upper bend, and, as an extra precautionary measure, Dikes A and B were planned to protect the convex bank about $\frac{3}{4}$ of a mile above the bridge site. At a point marked "Mud Bar" (see Plate XXXVII), a stratum of hard blue clay existed, which, in a measure, had protected the convex bank immediately below it. This bar, however, as shown by the difference between the dotted and full lines, was wearing away at the rate of about 100 feet a year. During the fall and winter of 1887 the dikes heretofore mentioned were constructed. Dikes 1, 2, 3, 4, 5 and 6 were constructed as submerged dikes, in the following manner: a foundation mattress was first constructed on inclined ways on the river bank above the location of the dikes as follows: a lattice foundation was laid upon these ways, consisting of 2 x 6-inch strips of timber, crossing each other at intervals of 4 feet; hard wood pins were placed at the intersections of these timbers, in holes bored for the purpose, and extending some $2\frac{1}{2}$ feet in height; around these pins long willows, from 15 to 20 feet in length, were woven to a depth of 2 feet; cross binders of 2 x 6-inch timbers were then placed on top of the mattress, holes being bored through them to receive the pins; the tops of the pins were then split, wedges inserted and driven to place, securely binding the entire mattress together. These mattresses were generally 60 feet wide by 100 feet long. After being completed they were launched into the river, and, being held by lines from the shore, were floated into position, the in-shore end resting against the shore; the lines holding these mattresses were so arranged that, after sinking the mattress, by pulling a check line they could be detached and secured. After the mattress was floated into position, barges loaded with rock were brought alongside and stone thrown upon the mattress. The greatest weight was placed upon the upper part of the mattress, and as it slowly sank below the water the barge was floated over it until it was entirely covered, the current assisting in sinking the mattress. After the mattress was sunk to the bed of the river, additional stone was thrown upon it until it was covered with about 2 feet of rock; an additional mattress was then constructed and sunk upon it. This was continued

until the dike was brought to the height planned, each succeeding mattress being smaller in its several dimensions than the one below it. Where these dikes were constructed in water 25 feet deep 100 feet from the shore, they consisted of three mattresses, and the entire dike was covered with a layer of rock about 2 feet thick. The crest of these dikes sloped about 5 to 1 as originally constructed, it being the intention to have the dikes cause as little resistance to the flood waters as possible, to the end that the smallest amount of eddy should be created. Dikes A and B were constructed after the river had frozen over, and were built upon the ice directly over the location of the dike; the ice was then cut around the dike, in order that the weight of the material of which it consisted might cause it to sink; the ice on the upper end being cut first, the pressure of the current assisted in sinking the dike, and the buoyancy of the ice caused it to shoot out from underneath; afterward additional rock was placed upon the shore end of the dike, securing a firm connection with the shore. The long dike "C" consisted of a foundation mattress 40 feet wide, 2 feet thick, covered by 18 inches of rock, constructed in place. This dike was 700 feet long. At the outer end an ice breaker, consisting of a pile of rock 9 feet high and 80 feet long, was constructed. Between this ice breaker and ordinary high water mark two rows of piling were driven through the mattress, the rows being 8 feet apart, and the piles being 10 feet apart in the rows. A close wattling consisting of 2 x 4-inch scantling was woven in and around this piling in such a manner as to retard the current in order to cause a deposit above and below the dike. The top of this wattle fence, at the shore end, was 13 feet above low water, sloping to 9 feet above low water at the outer end. The flood of 1888, which was the first flood that occurred after the construction of the dikes mentioned above, rose to an elevation of 17 feet above low water, and caused the deposit of a heavy bar above and below Dike "C," about ¾ of a mile long, and from 500 to 600 feet in width, the elevation of the top of the bar being, on an average, 13 feet above low water. In June of 1888, after the subsidence of the spring floods, a survey was made, and is indicated on Plate XXXVII by a full black line. The difference between the dotted line marking the shore line of August, 1887, and the full line, shows the change that occurred during the spring floods of 1888. It will be noted that at the location of Dikes A, B, 1, 2, 3, 4, 5 and 6, the two shore lines are coincident ; but immediately below Dikes 1, 2, 3, 4, 5 and 6 cutting

occurred in the form of scallops; this cutting was caused by the return action of the eddies generated by the current around the ends of the dikes, but, as shown on the sketch, the general shore line in the lower part of the upper bend was substantially maintained and additional land made advancing the shore line in the lower bend above and below Dike "C." After the spring flood Dike 7 was constructed. During the autumn of 1888, additional mattresses were sunk in the eddies on the flanks of the different dikes, the bank sloped above them and rip-rapped. Soundings taken in the fall of 1888 showed that the dikes in the upper bend had gradually settled at their outer ends, and that the slope of the crests of the dikes had steepened to about 1½ to 1 at the outer ends of the dikes, changing the slope of the crests of the dikes to a convex form. The channel had also deepened opposite the dikes from 25 to 50 feet, the greatest depth of water occurring some 50 feet below the outer points of the several dikes. The floods of 1889 have caused no additional changes to the shore line, and the object of the protection works has been obtained so far at a very reasonable cost, 4 miles of river being controlled at an expense, to date, of about $60 000.

SUPERSTRUCTURE.

By W. H. Breithaupt, M. Am. Soc. C. E.

The superstructure, resting on masonry, consists of three main spans of 400 feet each, flanked on the south, here the bluff side of the river, by one 200-foot span, and on the north, in the order named, by one 250-foot span, two 175 foot spans and 1 900 feet of viaduct, the whole being on a tangent, the truss spans level, and the viaduct track on a grade of 0.8 foot to the hundred. The three 400-foot spans are through spans; on all other parts of the bridge the track is uppermost. In the 400-foot, 200 foot and 250-foot spans there are iron stringers and floor beams; in the 175-foot spans and in the viaduct spans the ties rest directly on top chords of the trusses and girders respectively.

Span lengths as above given are from center to center of piers. Lengths, center to center of end pins, and other general dimensions of the various spans, are as follows:

400-foot spans.—Length, center to center, of end pins, 396 feet.
Number of panels, 16; panel length, 24 feet 9 inches.
Height, center to center, of chord pins, 50 feet.
Width, center to center, of trusses, 21 feet.

200-foot span.—Length, center to center, of end pins, 197 feet 6 inches.
Number of panels, 8; panel length, 24 feet 8¼ inches.
Height, center to center, of chord pins, 25 feet.
Width, center to center, of trusses, 17 feet.

250-foot span.—Length, center to center, of end pins, 247 feet 1 inch.
Number of panels, 10; panel length, 24 feet 8½ inches.
Height, center to center, of chord pins, 30 feet.
Width, center to center, of trusses, 17 feet.

175-foot spans.—Length, center to center, of end pins, 172 feet 6 inches.
Number of panels, 9; panel length, 19 feet 2 inches.
Height, center to center, of chord pins, 25 feet.
Width, center to center, of trusses, 14 feet.

On Piers Nos. 7 and 8, *i. e.*, under adjoining ends of the two 175-foot spans, and where viaduct adjoins 175-foot span, there are pyramidal iron towers, 22 feet high, which effect a considerable saving in masonry.

The structure is proportioned for maximum strains resulting from the following loading and wind pressure:

Static Load.—Total iron and steel weight, plus floor weight of 480 pounds per running foot for wood and rails.

Moving Load.—Two 86-ton consolidation engines followed by train load of 3 000 pounds per running foot, as per diagram.

Wind Pressure.—On loaded chords, 30 pounds per square foot on train and two surfaces of one truss; on unloaded chords, 50 pounds per square foot on two surfaces of one truss.

In proportioning sections the Launhardt formula was used for the 400-foot spans, but not for the shorter spans. Assumed unit strains are as follows:

400-foot spans.—*Tension.*—Main tie and bottom chord bars (steel), per square inch,

$$12\,000\left(1+\frac{\text{minimum stress in member}}{2\times\text{maximum stress in member}}\right)\text{ pounds.}$$

Strains, however, nowhere to exceed 14 000 pounds per sqare inch.

Counter ties (steel), 8 000 pounds per square inch.

Suspenders (steel), 10 000 pounds per square inch.

Lateral rods, steel, 18 000 pounds per square inch; iron, 15 000 pounds per square inch.

Wind strains in bottom chords, per square inch.

$$15\,000\left(1+\frac{\text{minimum stress in member}}{2\times\text{maximum stress in member}}\right)\text{pounds.}$$

For tension in any built members $\frac{1}{7}$ less than for bars or rods.

Flanges of floor-beams or stringers, 8 000 pounds per square inch.

Compression.—For posts, struts or top chords use

$$\text{formula } b=\frac{s}{1+\dfrac{l^2}{a\,r^2}}$$

In which b = permissible stress per square inch.
l = length of member in inches.
r = least radius of gyration.
a = 40 000 for columns with two flat ends.
= 30 000 for columns with one flat and one pin end.
= 20 000 for columns with two pin ends.

$$s=10\,000\left(1+\frac{\text{min. stress in member}}{2\text{ max. stress in member}}\right)$$

for end posts and top chords (steel).
= 8 000 for intermediate posts (iron).
= 12 000 for struts (iron).

Flanges of floor beams and stringers, 6 000 pounds per square inch.

Shear.—In webs of floor beams and stringers, 4 000 pounds per square inch.

In rivets and pins, 7 000 pounds per square inch.

Section of rivets in field connections of stringers and floor beams to be increased by 25 per cent.

Bearing.—On rivets and pins, 12 000 pounds per square inch.

Extreme fiber strain on pins, 15 000 for iron, 20 000 for steel.

Permissible pressure of bed plates on masonry, 250 pounds per square inch.

Permissible pressure on expansion rollers $\sqrt{540\,000\ d.}$ $d =$ diameter of roller.

All other spans and viaduct:

Tension.—Main ties and bottom chord bars, 12 000 pounds per square inch (steel).

Counters, 8 000 pounds per square inch (steel).

Compression.—For posts and top chords (iron), use formula $b = \dfrac{s}{1 + \dfrac{l^2}{r^2}}$ in which $s = 8\,000$. All other values same as given under 400-foot span.

All other unit strains same as given under 400-foot span.

The main tension members, chord pins and flat laterals in all truss spans are of tension steel; top chords and end posts of the 400-foot spans are of compression steel (rivets in them being of tension steel of the maximum ductility given in table); otherwise iron is used.

Steel is specified as follows:

No steel which proves brittle shall be used under any circumstances. If it develops this character at any stage of its manufacture or working, it shall at once be condemned.

All steel for the same span and the same class of work shall be made by the same process and at the same works.

A sample bar ¾ of an inch in diameter shall be rolled from every melt for preliminary tests. If this bar fails to meet requirements, the whole charge may be rejected.

Test pieces of finished steel may be cut either lengthwise or crosswise from the originals.

In addition to regular tests, daily cold bending tests shall be made as often as practicable during the manufacture, by bending double under the hammer such scraps as may be sheared off from the steel being worked.

Tension steel shall stand such forge tests, both hot and cold, as may be sufficient, in the opinion of the engineer, to prove soundness of the material and fitness for the service.

Specimens cut lengthwise and crosswise must, after being heated to a low cherry red, and cooled in water of the temperature of 82 degrees Fahrenheit, stand bending double, in a press or under the hammer, to a curve of which the diameter is twice the thickness of the piece.

No steel must be worked at a black heat.

Requirements for steel and iron are as per following table:

Material.	Ultimate strength per square inch.	Minimum limit of elasticity per square inch.	Per cent. of elongation in 12 diameters.	Per cent. reduction of area at fracture.	Cold Bending.	
					Angle to which specimens must bend without breaking.	Diameter of bend in terms of thickness of specimen.
Iron:					Degrees	
Bar Iron	52 000 $\frac{\text{5 000 by area of original bar}}{\text{circumference of original bar}}$	26 000	18	25	180	$1\frac{1}{2}$
Channels and I Beams, Flange	50 000	26 000	15	20	140	$1\frac{1}{2}$
Channels and I Beams, Web	47 000	25 000	12	18	140	2
Angles	50 000	26 000	15	20	140	$1\frac{1}{2}$
Plates, Under 18″ wide	50 000	26 000	13	18	140	2
Plates, 18″ to 36″ wide	48 000	25 000	10	15	140	3
Plates, 36″ to 54″ wide	47 000	25 000	8	12	90	
Plates, Over 54″ wide	46 000	25 000	8	12	90	
Steel:						
Compression	75 000 to 85 000	40 000	18	35	180	2
Tension	60 000 to 70 000	35 000	23	42	180	1

Wood in ties and guard rails is well seasoned white oak.

The trusses in the 400-foot spans are of the Whipple, double intersection, type; all other trusses are of the Pratt type. Tension members in general are eye-bars or rods, with die forged heads made in every case wholly by upsetting. Compression members are built of plates and angles, except in the viaduct, where they are of channels. End posts and top chords are trough shaped, with the open sides latticed; inter-

mediate posts have two plate and angle sides and two latticed sides; lateral struts are generally from angles with single latticing for central web, the whole forming a double T section. Flanges are in all cases turned outward. All girders and other beams are built of plates and angles. I beam sections are nowhere used. In packing of eye-bars on pins, pin moments are reduced where practicable, by pairing the bars so as to give minimum resultant moment.

The stringers are in four lines, two main stringers almost directly under the rails, figured for the total loading, and two side stringers, under outer guard rail, of half the strength of main stringers, to act in case of derailment only. The stringers being of an average length of almost 25 feet, it was found economical to use plates in the flanges, in addition to the flange angles. In bottom flanges there is one cover plate, put on as usual, while in top flange, rivet heads being undesirable on tie bed, the required central section is obtained by laying a narrow plate on the vertical leg of each angle. End stringers attach to end floor beams, and nowhere rest directly on piers, so that each span rests wholly on its four pedestals. Ties, except where otherwise described, are 8 inches by 8 inches by 16 feet, spaced 14 inches between centers. There is an inner iron guard rail 8 inches from track rail, and an outer oak guard rail, 18¼ inches from inside of main rail. The oak guard rail is protected on its inner edge by a 2 by 3-inch square root iron angle. (See floor cross-section, Plate XLIV.)

Lateral and sway systems are in every case adjustable, except between girders of viaduct, where stiff bracing is used. Adjustment is by means of a sleeve nut or by clevises, a clevis being used for fork end where two rods of adjacent panels, one in each, come on the same pin.

Further features of the various parts of the superstructure are as follows:

400-*foot Spans.*—Diagonals in the trusses are in two lengths, joined by a pin passing through the center of the intermediate post. Pin hole in the post for this pin is enlarged, leaving room for both post and diagonal to assume their proper directions when span deflects, without distorting either. The post is figured for its full length from pin to pin of chords. Sway rods 1 inch square are at every panel point. Depth of sway bracing from center to center of struts is 23 feet 8 inches. The portals are in one web, covering the upper half of end elevation of span,

made of 3 inch by 3 inch by $\frac{3}{8}$ inch intersecting angles, with heavy ornamental struts at top and bottom. Clearance from top of track rail to bottom of portal is 19 feet.

Bottom chords in Panels 1 and 2 from ends are stiff members, being built of plates and angles. There is a horizontal end stiffening strut from the center of the first intermediate post to the center of the end post.

The open sides of intermediate posts are parallel to the center line of the bridge. Floor beams are riveted to posts directly above bottom chord pins, the posts being stiffened, where floor beams attach, by means of a center web. The bottom lateral rods attach to lower flanges of floor beams, which form the bottom lateral struts.

200-*foot and* 250-*foot Spans.*—These spans have each one square and one inclined end. Intermediate sway rods 1 inch square extend the full depth of the trusses. At inclined ends bottom lateral system transmits to top through vertical system at first panel point.

The floor beams rest on top chords directly over posts, and have longitudinal knee braces at their outer ends.

The top lateral rods attach to a plate lying on the top chord and serving as base plate to the floor beam, being riveted to both. This makes a compact and effective connection.

175-*foot Spans.*—In these spans the ties—8 inches x 14 inches x 16 feet, spaced 14 inches center to center—rest directly on the top chords, which are proportioned for both their stress as truss members, and for the bending stress resulting from their direct loading. Continuity of chords brings, with the lower reinforce angles at panel points, the points of contrary flexure 2 feet 1 inch out from pin on either side, so that bending moments need to be taken in the middle 15 feet only of each section. Only the top flange of chord needs addition of material for strain due to bending, as in the bottom flanges, such strain is tension to which is opposed its regular compression strain as truss member. This extra section in top flange is in angles *a a*, which are 14 feet 8 inches long along central part of each chord panel.

Lateral and sway bracing is similar to that in other spans, with the only difference that there are struts in the loaded chord lateral system, there being no floor beams.

Viaduct.—(Plate XLVII). The 1 900 feet of iron viaduct consists of one 58-foot 9-inch girder next to truss span, followed by twenty-one 30-foot and twenty 60-foot 6 inch girders, resting on double bents, forming towers under the 30-foot spans. The girders are spaced 10 feet, center to center; 10-inch x 10-inch x 12-foot ties, spaced 16 inches between centers, and resting directly on girders, carry the track. A foot walk 5 feet wide, resting on wooden brackets fastened to sides of the girders, extends the entire length of the iron viaduct. The longer girders have a depth of 5 feet and the shorter a depth of 3 feet. Bearing on bents is arranged by having in the end of the longer girder a recess of equal depth with the shorter girder. The longer girder rests on the bent and the shorter on the longer. Provision for expansion and contraction is made by having both girders slide on each other and on bent, on every south bent of towers, and having both fixed on every north bent. To bring girders of unequal depth to a common bearing by bending upward the bottom flanges of the longer girder, and reducing depth of its web, entails expensive shop work in the bending of the heavy flange angles, and was for that reason avoided. Arrangement as above necessitates a top longitudinal strut in the tower, but such a strut is a desirable feature anyway. Webs in all girders are $\frac{3}{8}$ inch, with flanges, of section depending on length of girder, made up of angles and cover plates. Lateral and sway bracing between the girders, which is of angles, consists in a horizontal system riveted to under side of top flanges, and in cross-frames of the same depth as the girders. There are seven such cross-frames in the longer and four in the shorter spans. Web stiffeners come at the cross-frames, and half way between them, and are in every case of two 3-inch x 3-inch $\frac{3}{8}$-inch angles, one on each side of web. No filler plates are used under stiffeners; ends are bent to conform to flange angles. Special care was taken to have stiffeners fit in closely to flanges.

The towers are in two stories. Main columns in them are of a trough section, made of two channels and one plate, with open side latticed, the plates being on transverse outer sides of towers. The height of towers from top of pedestal capstone to bottom of girders varies with the grade from 53 feet $1\frac{1}{2}$ inches in Tower 2, to 38 feet $2\frac{3}{4}$ inches in Tower 21. Tops of masonry pedestals, on which towers rest, are level throughout.

The columns fasten to pedestals by means of four anchor bolts in

each. These anchor bolts, $1\frac{1}{8}$ inches in diameter, are built into the pedestals, are four feet or more long—length varying to accommodate thickness of stone courses—and head on plates imbedded in the masonry. The towers have a transverse batter of 1 in 6, at which batter the structure is slightly more than balanced with no tension on windward anchor bolts at maximum wind pressure. Longitudinally the towers have no batter. Longitudinal bracing is proportioned to resist the pull due to stopping of the assumed moving load, friction being taken at 20 per cent. of the load.

Workmanship and finish in superstructure throughout are very creditable. Tension members are made by the regular Edgemoor process, the heads being made in one operation, and are noticeable for their neat finish and uniform good quality.

But little trouble was experienced in getting material fulfilling specifications, and uniform for the various classes. In steel of over three hundred specimen tests, the averages were as follows:

For tension steel, limit of elasticity, 42 000; ultimate strength, 63 900; per cent. of elongation in 8 inches, 26.5; per cent. of reduction of area at fracture, 51.
For compression steel, limit of elasticity, 47 100; ultimate strength, 80 100; per cent. of elongation in 8 inches, 22.7; per cent. of reduction of area at fracture, 44.5.

A little less than 8 per cent. of all tests fell below requirements, and the bulk of these were but little under.

Tests on finished tension members (see Table No. 1) were on the whole very satisfactory.

Two compression specimens (see Plate XLVIII) being as nearly as feasible reduced fac-similes of top chord sections of the 400-foot spans, their size limited by the capacity of the largest testing machine available, were made specially for testing. They developed, fairly closely, the ultimate strengths, as determined by formula, it being in each case about four times the amount of permissible unit strain—(see Table No. 2 and Plate XLVIII). Elastic limit values, if taken as first "set" in shortening of length of specimens, were fully high, but varied considerably in the two specimens. They can only be considered as approximately determined by this test. Deflections showed "set" early in the tests; but such "set" was in each case, until test was well advanced, so extremely small as compared to length of the specimen, as to be of little importance.

Messrs. J. A. Colby and S. C. Weiskopf, M. Am. Soc. C. E., had charge of both mill and shop inspection of the entire superstructure.

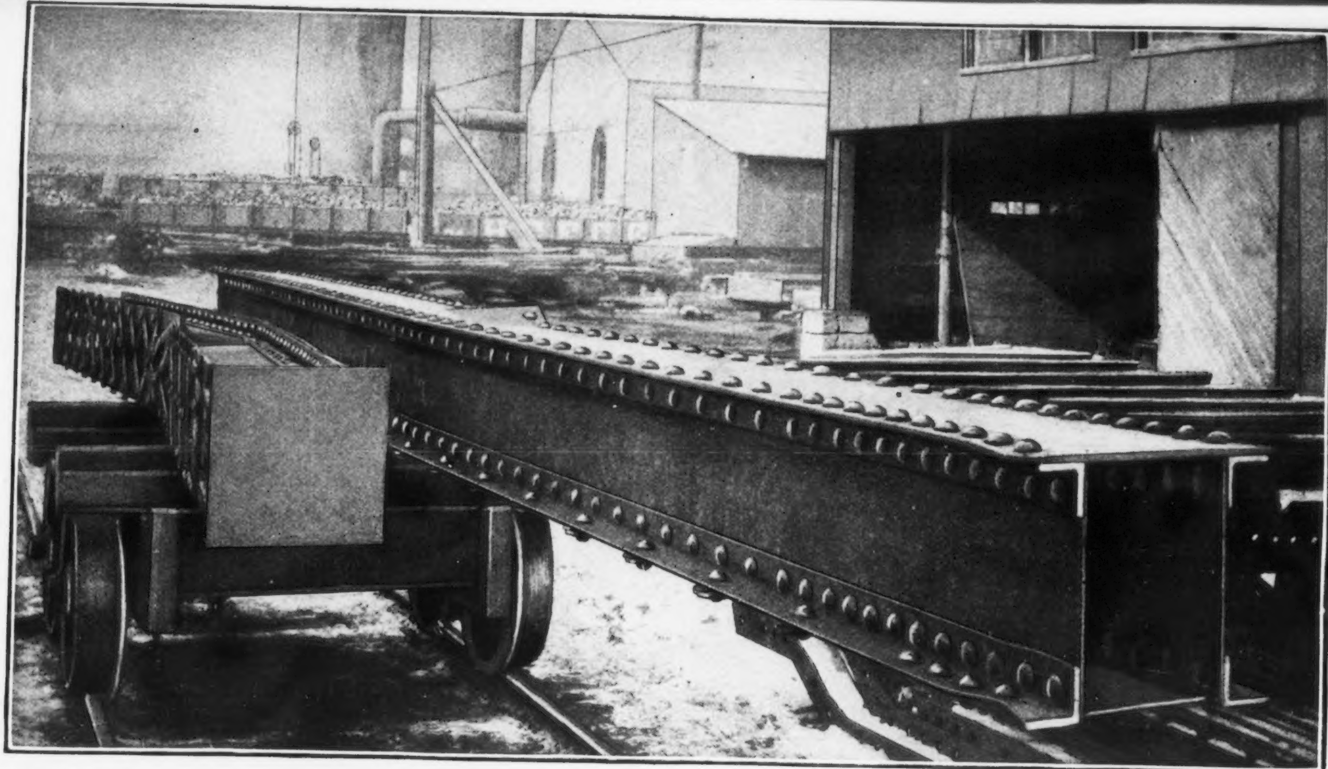


PLATE XXXV. COMPRESSION SPECIMENS AFTER TEST.

Vol

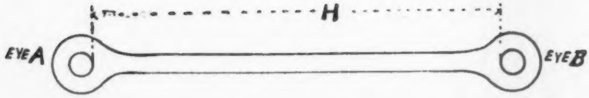
Sectio

Inche
5 x 1
"
5 x 1.
7 x 1
7 x 1
"

7 x 1

Sectio

Inche
4 x
3 x
3 x 1
4 x



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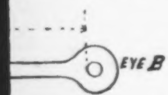
Section.	Mark and Span.	Area of Section.	H.	Eye A.			Eye B.		
				Diameter of Eye.	Diameter of Pin Hole.	Per cent. Excess over Bar.	Diameter of Eye.	Diameter of Pin Hole.	Per cent. Excess over Bar.
Inches.	Ft. In.	Sq. In.	Ft. In.	Inches.	Inches.		Inches.		
5 x 1	T_3 172 6....	5	31 $1\frac{5}{32}$	12.65	4.92	60.6	12.79	4.93	58.7
"	" "	"	"	12.67	"	59.4	"	"	60.3
5 x $1\frac{7}{16}$	T_2 "	7.19	"	12.62	"	52.9	12.48	"	51.2
7 x $1\frac{1}{4}$	CL_3 247 1....	8.75	24 $3\frac{1}{16}$	15.75	5.47	44.4	15.81	5.47	47.7
7 x 1	BL^{3B} 396	6.97	24 3	15.87	5.97	43.5	15.87	5.97	42.1
"	" "	6.90	"	15.82	"	39.7	"	"	43.4
7 x $1\frac{3}{4}$	BL_{3A} "	12.3	"	15.75	"	42.	15.75	"	37.2

Section.	Mark and Span.	Area of Section.	H.	Eye A.			Eye B.		
				Area of Section.	Diameter of Pin Hole.	Per cent. Excess over Bar.	Area of Section.	Diameter of Pin Hole.	Per cent. Excess over Bar.
Inches.	Ft. In.	Sq. Inches.	Ft. In.	Sq. Inches.	Inches.		Sq. Inches	Inches.	
4 x $\frac{15}{16}$	CT_4 172 6....	3.75	31 $1\frac{5}{32}$	5.53	$4\frac{15}{16}$	47.7	5.6	$4\frac{15}{16}$	49.4
3 x $\frac{15}{16}$	R_0 "	2.81	22 $3\frac{3}{4}$	4.61	$3\frac{1}{4}$	64.1	4.58	$3\frac{1}{4}$	63.2
3 x $1\frac{1}{4}$	CR_0 247 1....	3.75	27 $10\frac{5}{8}$	5.73	$3\frac{7}{16}$	52.5	5.83	$3\frac{7}{16}$	55.5
4 x $\frac{11}{16}$	ACT_3 197 6....	2.75	32 10	3.66	$5\frac{7}{16}$	33.	3.81	$4\frac{15}{16}$	38.5

TABLE No. 1.—Tests on Finished Eye-bars

Eye B.			Elastic Limit. Pounds per Square Inch.	Ultimate Strength. Pounds per Square Inch.	Per cent. of Elongation.			Per cent. Reduction of Area at Fracture.
er	Diameter of Pin Hole.	Per cent. Excess over Bar.			In 8 Inches.	In —.	In H.	
.						Ft. %		
	4.93	58.7	44 484	68 950	37.5	29—12.2	11.76	47.5
	"	60.3	44 484	65 984	"	" —13.9	13.34	45.68
	"	51.2	40 210	65 990	37.75	" —13.2	12.58	48.54
	5.47	47.7	39 825	64 395	43.	22—14.5	13.5	48.5
	5.97	42.1	43 611	68 608	36.6	" —13.5	11.2	49.3
	"	43.4	41 905	66 618	45.	" —12.5	11.8	57.2
					In 12 in.			
	"	37.2	35 776	59 197	37.5	" —13.9	13.6	42.7



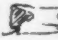
Eye B.			Upset.		Elastic Limit. Pounds per Square Inch.	Ultimate Strength. Pounds per Square Inch.	Per Cent. of Elongation.			R
on.	Diameter of Pin Hole.	Per cent. Excess over Bar.	Diameter.	Length.			In 8 inches.	In —.	In H.	
hes	Inches.		Inches.	Inches.						
	$4\frac{15}{16}$	49.4	$2\frac{7}{8}$	$5\frac{1}{8}$	45 470	48 450	Broke at union of bar			
	$3\frac{1}{4}$	63.2	$2\frac{1}{2}$	5	48 810	69 920	30.	21′—10.4	9.86	
	$3\frac{7}{16}$	55.5	$2\frac{7}{8}$	$5\frac{1}{2}$	44 480	67 200	11.25	26′— 7.8	7.51	
	$4\frac{15}{16}$	38.5	$2\frac{1}{4}$	$4\frac{3}{4}$	47 180	70 097	37.25	32′—14.9	4.6	

EYE-BARS

Per cent. Reduction of Area at Fracture.	Elongation of Pin Holes.		Location of Fracture.	Description of Fracture.	Blow No.	M	
						On Preliminary	
	Eye A.	Eye B.				Elastic Limit.	Ulti Stren
	Inches.	Inches.	Ft. In.				
47.5	0.43	0.68	1 7½ from Eye A..........	Silky........................	246 986	44 830	68
45.68	0.56	0.66	7 9½ " " "	Cupped center; hard edges....	247 141	42 441	62
48.54	0.72	0.76	7 2 " " "	Silky " " " ..	247 020	42 440	65
48.5	1.28	1.33	1 8 " " B..........	Granular; jagged.............	246 321	42 790	63
49.3	1.19	1.27	1 8½ " " A..........	Silky; granular edges	248 782	42 790	63
57.2	1.49	1.25	2 3½ " " "	" ½ cup. " "	246 631	47 900	64
42.7	1.38	1.34	2 3 " " "	50 % silky. " granular. 			

TION.	Per cent. Reduction of Area at Fracture.	Elongation of Pin Holes.		Location of Fracture.	Description of Fracture.	Blow No.	M	
							On Preliminary	
In H.		Eye A.	Eye B.				Elastic Limit.	Ult Str
ion of bar to upset.				All others then carefully reannealed.		252 048	46 590	69
9.86	53.46	0.15	0.15	3' 5½" from Eye A......	Silky.....................	251 334	46 260	66
7.51	8.92	0.31	0.18	1' 11" " " "......	Square.....................	251 287	43 230	64
4.6	60.8	0.32	0.54	9' 10" " " B.......	Silky, cupped.............	251 284	43 780	65

HED EYE-BARS.

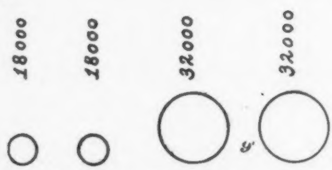
	Per cent. Reduction of Area at Fracture.	Elongation of Pin Holes.		Location of Fracture.	Description of Fractu
		Eye A.	Eye B.		
		Inches.	Inches.	Ft. In.	
5	47.5	0.43	0.68	1 7½ from Eye A...........	Silky...... ....
4	45.68	0.56	0.66	7 9½ " " "	Cupped center; hard ed
3	48.54	0.72	0.76	7 2 " " "	Silky " "
	48.5	1.28	1.33	1 8 " " B...........	Granular; jagged........
	49.3	1.19	1.27	1 8½ " " A...........	Silky; granular edges .
	57.2	1.49	1.25	2 3½ " " "	" ½ cup. " " .
	42.7	1.38	1.34	2 3 " " "	50 % silky. " granular. 

GATION.		Per cent. Reduction of Area at Fracture.	Elongation of Pin Holes.		Location of Fracture.	Description of Fr
	In H.		Eye A.	Eye B.		
t union of bar to upset.					All others then carefully reannealed.	
	9.86	53.46	0.15	0.15	3' 5½'' from Eye A......	Silky...........
	7.51	8.92	0.31	0.18	1' 11" " " ".......	Square...........
	14.6	60.8	0.32	0.54	9' 10" " " B.......	Silky, cupped... .

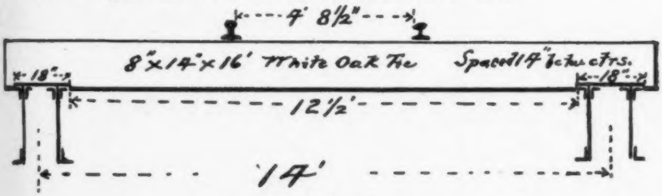
Fracture.	Blow No.	Material Tests on same Blow Numbers.					
		On Preliminary ¾-inch Rounds.			On Specimens from Rolled Bars.		
		Elastic Limit.	Ultimate Strength.	Per cent. Elongation in 8 Inches.	Elastic Limit.	Ultimate Strength.	Per cent. Elongation in 8 Inches.
. ...	246 986	44 830	68 040	25.	......	......	......
ard edges....	247 141	42 441	62 300	29.6	39 190	66 620	30.5
" " ..	247 020	42 440	65 600	28.	33 540	61 450	27.1
....	246 321	42 790	63 490	29.7	......	......	......
dges	248 782	42 790	63 250	29.1	34 620	61 500	28.
"	246 631	47 900	64 770	27.	37 700	61 210	27.

of Fracture.	Blow No.	Material Tests on same Blow Numbers.					
		On Preliminary ¾-inch Rounds.			On Specimens from Rolled Bars.		
		Elastic Limit.	Ultimate Strength.	Per cent. Elongation in 8 Inches.	Elastic Limit.	Ultimate Strength.	Per cent. Elongation in 8 Inches.
	252 048	46 590	69 420	26.6			
....	251 334	46 260	66 460	25.4	42 490	66 740	29.4
....	251 287	43 230	64 280	25.4	36 710	62 660	25.1
ed..	251 284	43 780	65 000	25.2			

On the 175-foot spans where ties rest directly on top chords, and the viaduct where they rest on main girders, the rail being in both cases well within tie support, deflection of ties under load was noted, with the following results:



Load—Engine with 18 *tons on truck,* 32 *tons on drivers.*



175-*foot span.*

Downward deflection of center of tie taken on three ties:

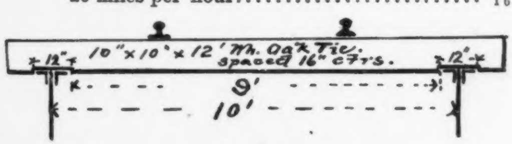
Deflections.

1st Tie.—Ordinary tie; rail bearings on it and on adjacent ties fair. Deflection with engine going at 15 miles per hour.............................. ¼ inch.

2d Tie.—Somewhat windshaky. One adjacent tie rail does not bear. Deflection with engine going at 20 miles per hour........................ ½ "

Deflection with engine stationary............. $\frac{7}{16}$ "

3d Tie.—A good tie; rail bearings on it and on adjacent ties good. Deflection with engine going at 20 miles per hour.......................... $\frac{5}{16}$ "



Viaduct.

Deflection taken on one tie only; a good ordinary tie, rail-bearings on it and on adjacent ties fair:

Deflection with engine going at 20 miles per hour....... $\frac{3}{32}$ inch.

SPECIMEN "B"

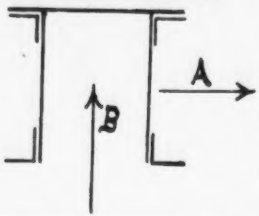


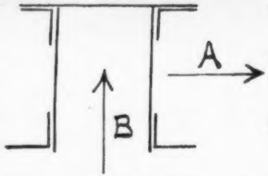
TABLE No. 2.—COMPRESSION TESTS.

TEST No. 1.

Member with two square ends.
All deflections recorded in directions of arrows.
Weight of member.................................... 1 640 pounds.
" counterbalance .... 205 "
Counterbalance applied at center of post, and suspended from arm, four times length of arm attached to post.

Load.	Deflections.				Contraction.		Load.	Deflections.				Contraction.	
	A.	Set.	B.	Set.	C.	Set.		A.	Set.	B.	Set.	C.	Set.
Pounds.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Pounds.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
40 000	.00	.00	.05	.00	.03	.00	400 000	.08	.07	.27	.09	.21	.00
80 000	.00	.00	.07	.00	.05	.00	420 000	.14	.10	.27	.09	.23	.00
100 000	.00	.00	.07	.00	.05	.00	440 000	.14	.10	.27	.09	.23	.00
120 000	.00	.00	.08	.00	.06	.00	460 000	.20	.16	.27	.09	.23	.00
140 000	.00	.00	.10	.02	.08	.00	480 000	.22	.18	.29	.11	.25	.00
160 000	.00	.00	.12	.02	.09	.00	500 000	.22	.18	.30	.14	.27	.00
180 000	.00	.00	.12	.02	.10	.00	520 000	.23	.18	.33	.15	.27	.00
200 000	.00	.00	.13	.02	.11	.00	540 000	.23	.18	.33	.18	.28	.01
220 000	.00	.00	.15	.03	.11	.00	560 000	.23	.19	.34	.20	.29	.01
240 000	.00	.00	.17	.03	.12	.00	580 000	.25	.20	.35	.22	.30	.01
260 000	.03	.02	.20	.04	.12	.00	600 000	.26	.20	.40	.27	.30	.01
280 000	.03	.02	.22	.05	.13	.00	620 000	.26	.22	.40	.30	.32	.02
300 000	.03	.02	.22	.06	.13	.00	640 000	.26	.25	.44	.33	.32	.03
320 000	.03	.02	.24	.06	.15	.00	660 000	.30	.26	.58	.40	.34	.04
340 000	.03	.02	.24	.06	.20	.00	680 000	.38	.30	.60	.40	.35	.05
360 000	.04	.03	.24	.06	.20	.00	700 000	.48	.43	.72	.65	.39	.08
380 000	.06	.05	.27	.09	.21	.00	709 800	Failed in direction A and B.					

"SPECIMEN A"



TEST No. 2.

Member with one square and one pin end.
Weight of member.................................... 825 pounds.
" counterbalance.............................. 103 "
All deflections recorded in directions of arrows.
Deflection A recorded at center of member.
" B " 5 feet from center of pin.
Counterbalance applied at center of post, and suspended from arm, four times length of arm attached to post.

Tests made by COLBY & WEISKOPF, Inspectors.

Load.	Deflections.				Contraction.		Load.	Deflections.				Contraction.	
	A.	Set.	B.	Set.	C.	Set.		A.	Set.	B.	Set.	C.	Set.
Pounds.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Pounds.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
40 000	.00	.00	.04	.00	.00	.00	340 000	.17	.17	.17	.07	.13	.02
80 000	.08	.06	.06	.02	.00	.00	350 000	.17	.17	.17	.07	.13	.02
100 000	.09	.08	.07	.63	.01	.00	360 000	.17	.17	.17	.07	.14	.03
110 000	.09	.08	.07	.03	.01	.00	370 000	.19	.16	.18	.08	.14	.03
120 000	.09	.09	.07	.03	.02	.00	380 000	.17	.17	.18	.08	.14	.03
130 000	.09	.09	.07	.03	.02	.00	390 000	.17	.17	.19	.09	.15	.03
140 000	.10	.09	.08	.03	.03	.00	400 000	.17	.17	.20	.09	.15	.03
150 000	.11	.09	.09	.04	.04	.00	410 000	.17	.17	.20	.09	.16	.03
160 000	.11	.10	.09	.04	.05	.00	420 000	.17	.17	.20	.09	.16	.03
170 000	.11	.10	.09	.04	.05	.00	430 000	.17	.17	.20	.09	.16	.03
180 000	.11	.10	.10	.04	.05	.00	440 000	.17	.17	.21	.09	.16	.03
190 000	.11	.10	.11	.04	.06	.00	450 000	.18	.19	.21	.09	.16	.03
200 000	.15	.10	.11	.05	.06	.00	460 000	.19	.19	.21	.10	.17	.03
210 000	.15	.14	.12	.06	.07	.00	470 000	.19	.19	.21	.10	.17	.03
220 000	.15	.14	.13	.06	.07	.00	480 000	.19	.19	.22	.10	.17	.03
230 000	.15	.14	.13	.06	.08	.00	490 000	.19	.19	.22	.11	.17	.03
240 000	.15	.14	.14	.06	.08	.00	500 000	.19	.19	.22	.11	.18	.03
250 000	.15	.14	.14	.06	.08	.00	510 000	.19	.19	.23	.11	.18	.03
260 000	.15	.14	.14	.06	.09	.00	520 000	.19	.19	.24	.12	.20	.03
270 000	.15	.15	.14	.06	.09	.00	530 000	.19	.20	.24	.13	.20	.03
280 000	.15	.15	.15	.07	.10	.00	540 000	.20	.20	.24	.13	.20	.03
290 000	.15	.15	.16	.07	.10	.00	550 000	.20	.20	.27	.14	.23	.04
300 000	.15	.15	.17	.07	.10	.00	560 000	.21	.21	.29	.18	.23	.04
310 000	.16	.16	.17	.07	.10	.00	570 000	.21	.21	.32	.20	.25	.05
320 000	.16	.16	.17	.07	.11	.01	580 000	.21	.21	.36	.25	.26	.07
330 000	.16	.16	.17	.07	.12	.01	590 000	.21	.21	.45	.34	.28	.08
....	....	....	....	....	....	....	595 400	Failed in direction A and B.					

TABLE No. 3.

Superstructure Weights.

Part of Bridge.	Weights in Detail.		Total Weights.		Per cent. of Difference.	Steel or Iron.	
	Calculated from Detailed Drawings.	Scale.	Calculated.	Scale.		Steel.	Iron.
1 900′ Viaduct:							
Girders	958 638	958 820					
Columns	348 513	351 320					
Bracing............	480 146	483 742	1 787 297	1 793 882	+0.37	8 126	1 785 756
2—172′ 6″ spans:			439 200	442 800	+0.82	146 984	295 816
Pier columns.......			60 333	61 697	+2.26	......	61 697
1—247′ 6″ span:							
Trusses and bracing	395 750	405 612					
Floor..............	160 917	155 470	556 667	561 082	+0.79	145 734	415 348
3—396′ spans:							
Trusses and bracing	2 842 697	2 905 675					
Floor..............	781 939	792 420	3 624 636	3 698 095	+2.02	2 156 252	1 541 843
1—197′ 6″ span:							
Trusses and bracing	246 256	246 005					
Floor..............	129 126	125 290	375 382	371 295	—1.09	79 620	291 675
Totals.........	......	......	6 843 515	6 928 851	+1.25	2 536 716	4 392 135

DISCUSSION.

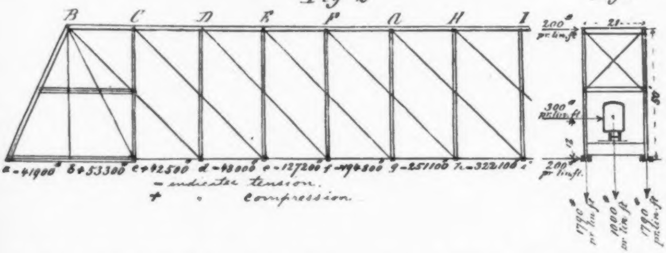
William Scherzer, M. Am. Soc. C. E.—The above paper must be considered a valuable contribution to our bridge literature. I was particularly interested in the description of the superstructure of the 400-foot spans, and will venture a few remarks on my observations. One peculiarity of a Whipple truss of long span, having a Pratt truss for a lower lateral system, is the tendency of the wind to produce compressive stresses in the second and third panels of windward lower chord. It is quite customary, in bridges of this type, to use stiff members in the two end panels of lower chord, but in no instance, to my knowledge, have these stiff members been used in the third panel.

A train of empty box cars weighing 1 000 pounds per lineal foot covering the entire length of span, and a wind force of 30 pounds per square foot on train and exposed surfaces of trusses, are the conditions necessary to produce compressive stresses in the panels mentioned above. For wind on trusses 400 pounds per lineal foot of bridge was assumed, one-half acting on upper and one-half on lower lateral system. This assumption may be considered low. Wind force on train was taken at 300 pounds per lineal foot, as usual. Weight of bridge, including floor, 3 580 pounds per lineal foot. Fig. 1 is a cross-section, showing

points of application of wind forces and vertical loads. It was further assumed that the entire upper wind forces pass through the inclined end posts to the abutments, thereby producing a moment whose horizontal component must be resisted by the lower chords. This moment produces compression in the windward lower chord, which is constant for all members.

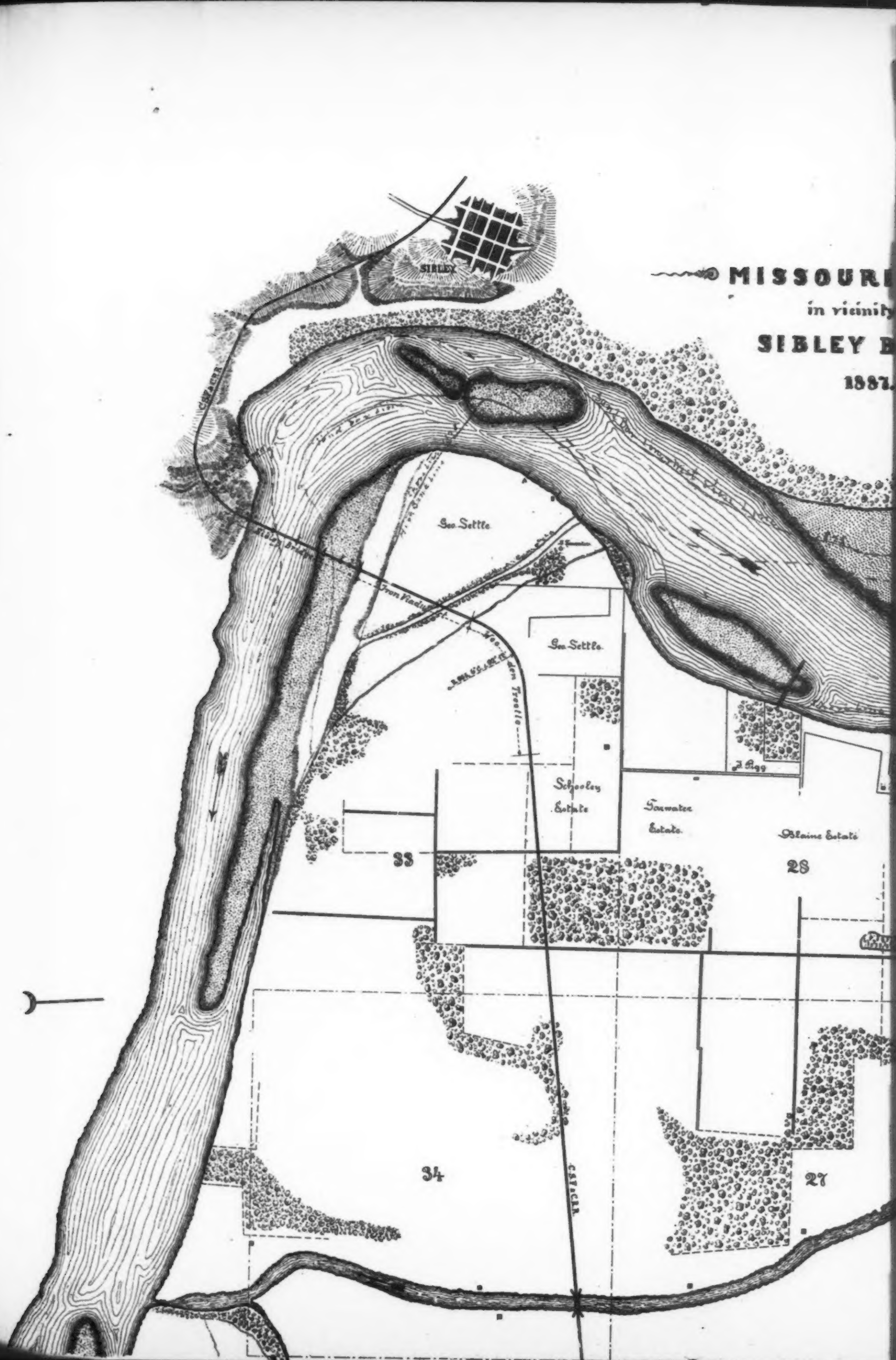
Fig. 2 is a diagram showing the resultant stresses due to wind, dead and live loads in lower windward chord. In this instance the second and third panels are the only ones which receive compression.

Fig 2 Fig. 1

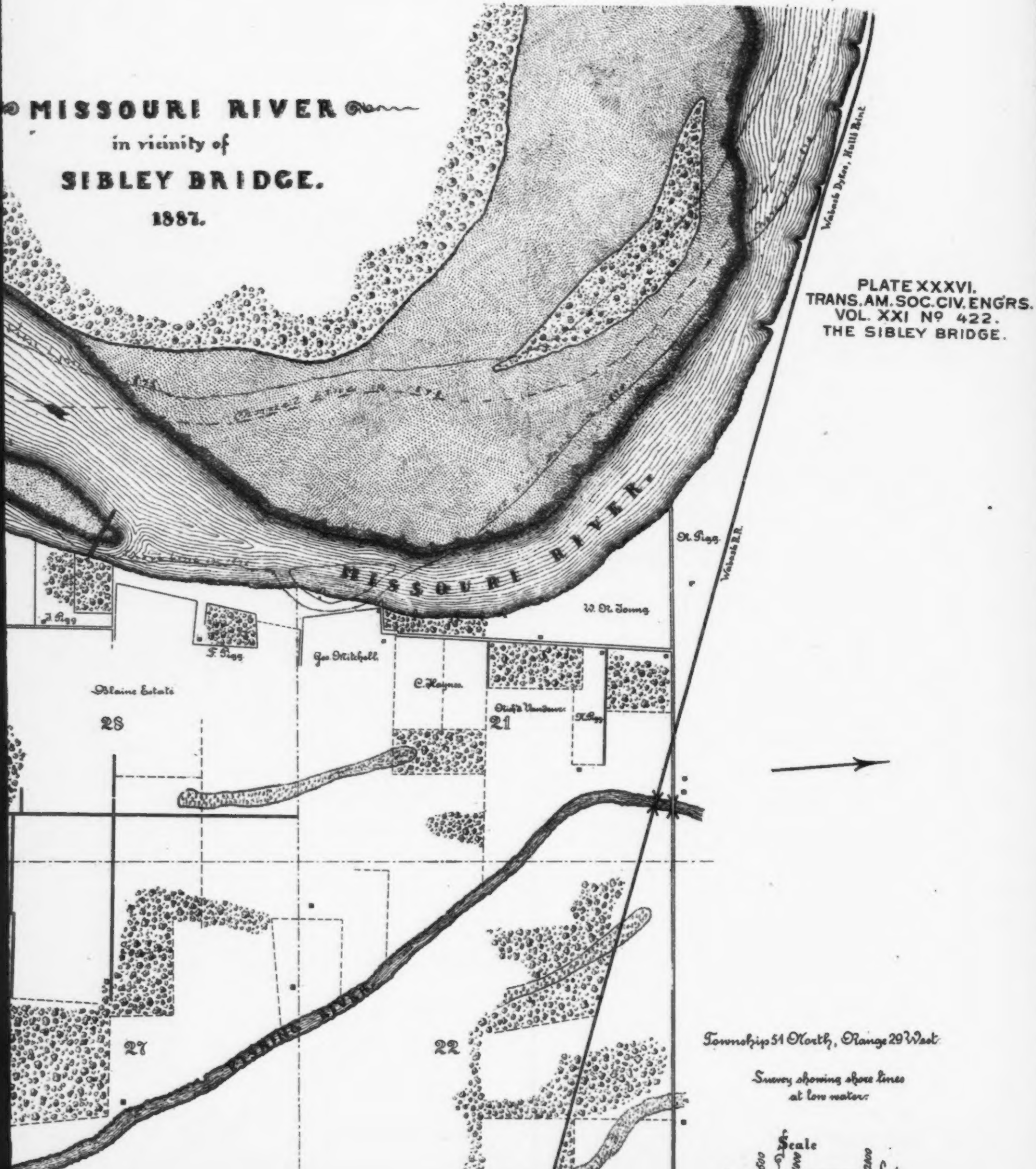


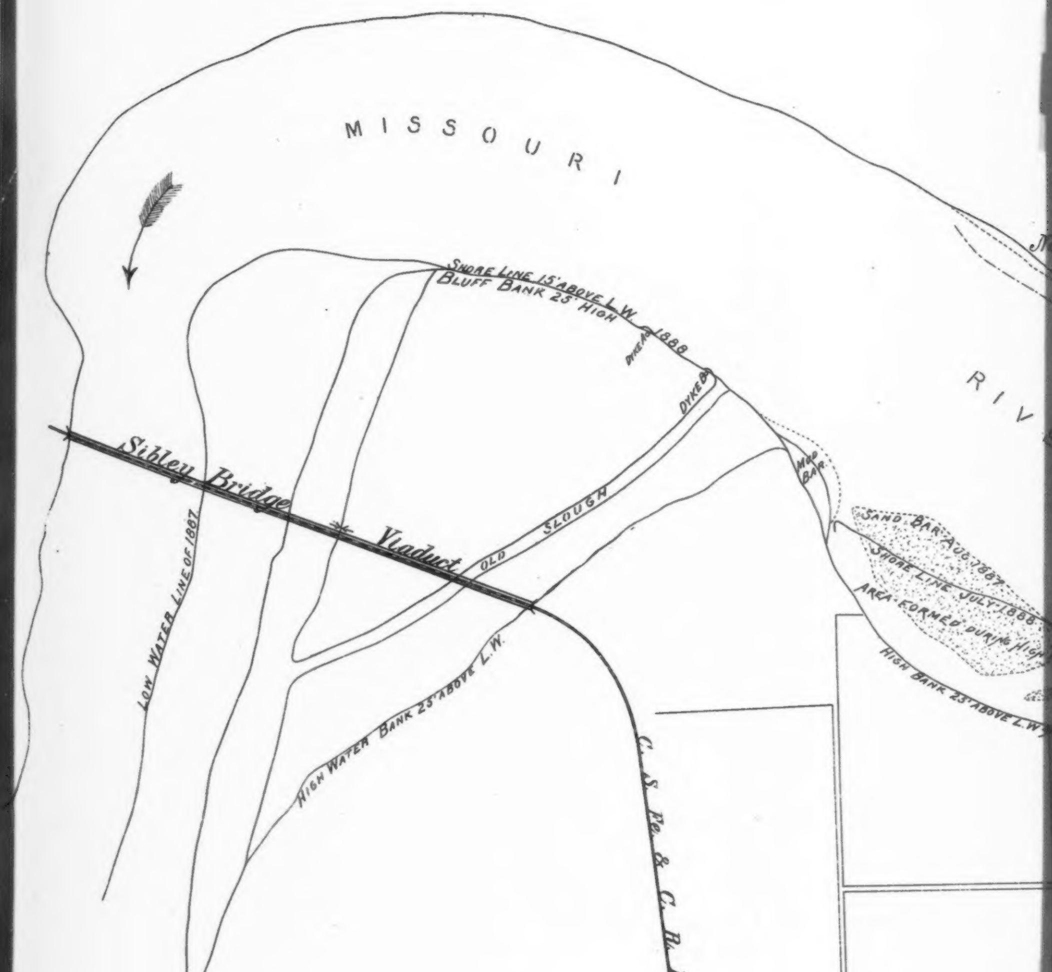
Enlarging the pin holes at the intersection of the diagonal suspension bars with the vertical posts will certainly relieve the posts of cross-strains during erection; but the bending stresses in posts due to the eccentricity of the lower lateral connections will thereby be increased, and it is an open question whether for this reason it would not be best to hold the posts midway. The end stiffening strut from the center of the first intermediate post to the center of inclined end post cannot be of any service, unless the point of intersection with the intermediate post be made fixed.

The illustrations accompanying the paper on the Sibley Bridge are:

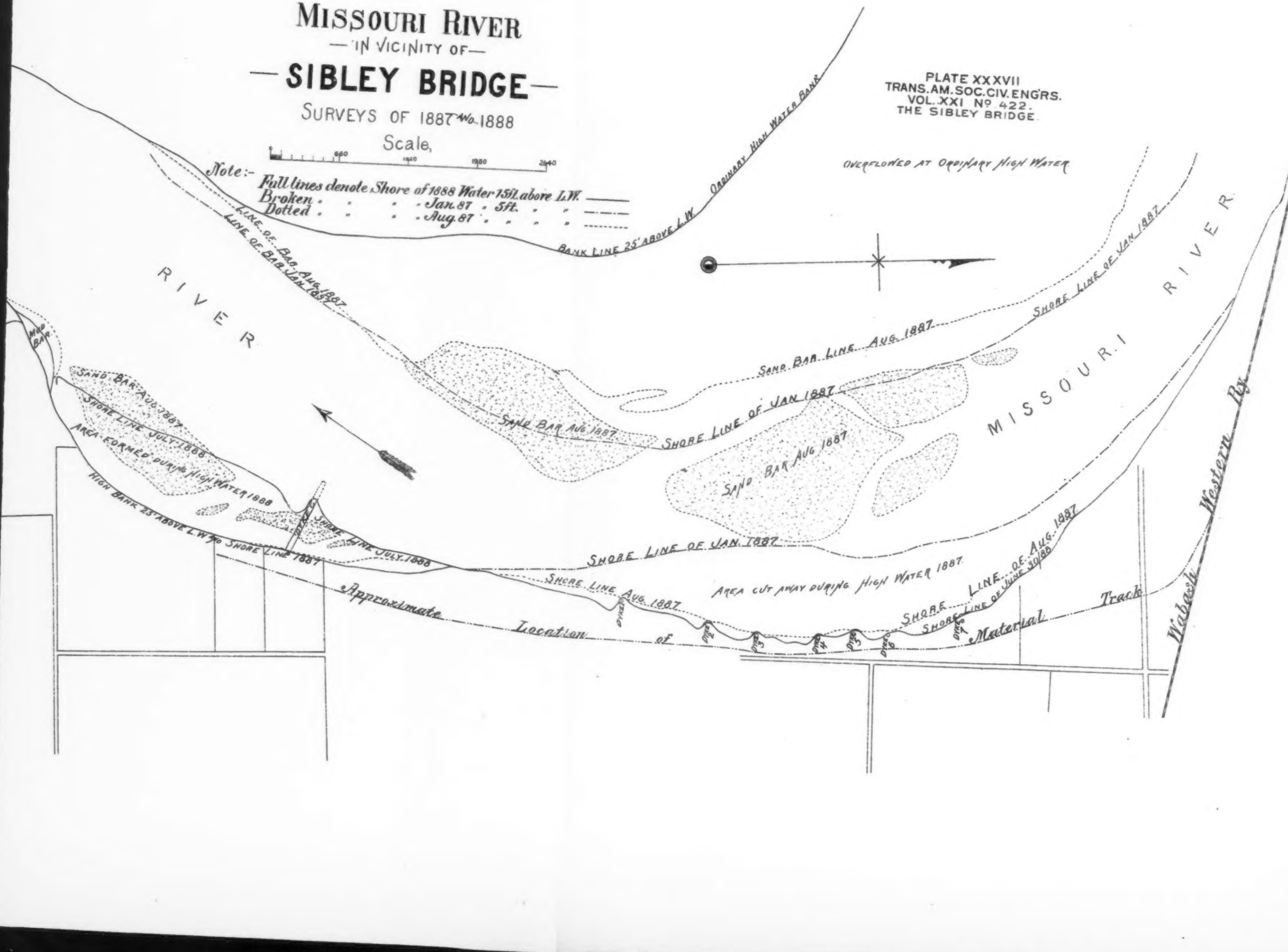


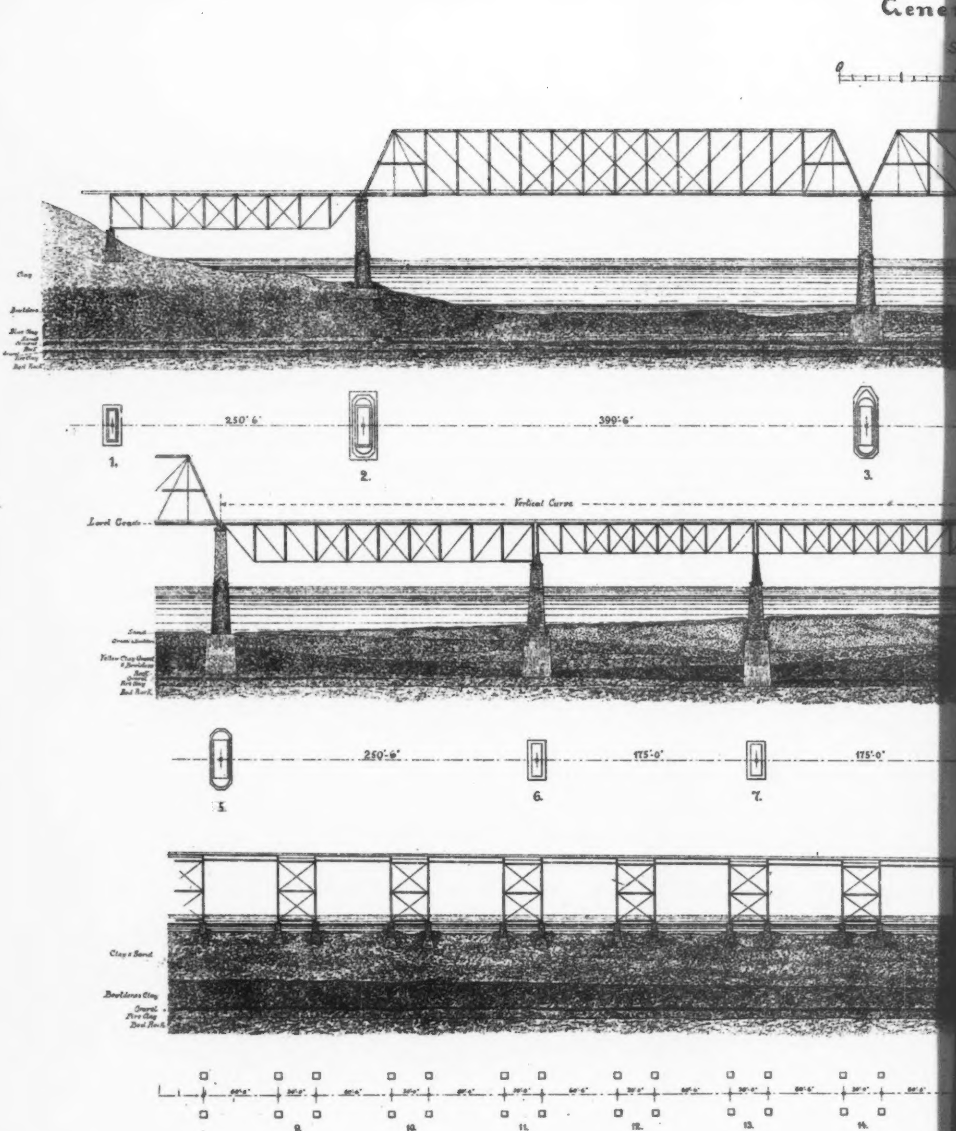
MISSOURI
in vicinity
SIBLEY B
1887.
SIBLEY
Geo. Settle
Geo. Settle
Iron Viaduct
Wooden Trestle
Schooley Estate
Estate
Blaine Estate
J. Rigg
33
28
34
27


MISSOURI RIVER
in vicinity of
SIBLEY BRIDGE.
1887.
PLATE XXXVI.
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XXI Nº 422.
THE SIBLEY BRIDGE.
MISSOURI RIVER
Wabash R.R.
W. M. Young
Geo Mitchell
C. Haynes
Blaine Estate
28
21
27
22
Township 51 North, Range 29 West
Survey showing shore lines
at low water.
Scale
500
1000
2000
feet.



MISSOURI
RIV
SHORE LINE 15' ABOVE L.W. 1888
BLUFF BANK 25' HIGH
Sibley Bridge
Viaduct
OLD SLOUGH
MUD BAR.
SAND BAR AUG. 1887
SHORE LINE JULY 1888
AREA FORMED DURING HIGH
HIGH BANK 23' ABOVE L.W.
LOW WATER LINE OF 1887
HIGH WATER BANK 23' ABOVE L.W.
C. S. Fe. & C. R. R.


MISSOURI RIVER
— IN VICINITY OF —
— SIBLEY BRIDGE —
SURVEYS OF 1887 and 1888
Scale,
660
1320
1980
2640
Note:- Full lines denote Shore of 1888 Water 15ft. above L.W.
Broken " " " " Jan. 87 . 5ft. " "
Dotted " " " " Aug. 87 " " " "
PLATE XXXVII
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XXI Nº 422.
THE SIBLEY BRIDGE.
ORDINARY HIGH WATER BANK
BANK LINE 25' ABOVE L.W.
OVERFLOWED AT ORDINARY HIGH WATER
LINE OF BAR AUG. 1887
LINE OF BAR JAN. 1887
RIVER
MUD BAR
SAND BAR AUG. 1887
SHORE LINE JULY 1888
AREA FORMED DURING HIGH WATER 1888
HIGH BANK 23' ABOVE L.W. TO SHORE LINE 1887
SHORE LINE JULY 1888
SAND BAR LINE AUG. 1887
SAND BAR AUG. 1887
SHORE LINE OF JAN. 1887
SAND BAR AUG 1887
SHORE LINE OF JAN. 1887
MISSOURI RIVER
SHORE LINE OF JAN. 1887
SHORE LINE AUG. 1887
AREA CUT AWAY DURING HIGH WATER 1887
SHORE LINE OF AUG. 1887
SHORE LINE OF JUNE 30/88
Approximate Location of Material Track
Wabash Western Ry.


Gener
Clay
Boulders
Bed Rock
250' 6"
399'-6"
1.
2.
3.
Vertical Curve
Level Grade
Sand
Bed Rock
250'-6"
175'-0"
175'-0"
6.
7.
Clay & Sand
Boulders & Clay
Gravel
Fire Clay
Bed Rock
9.
10.
11.
12.
13.
14.

General Profile.

Scale
0 100 200 ft.

PLATE XXXVIII.
TRANS. AM. SOC. CIV. ENG'RS.
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THE SIBLEY BRIDGE.

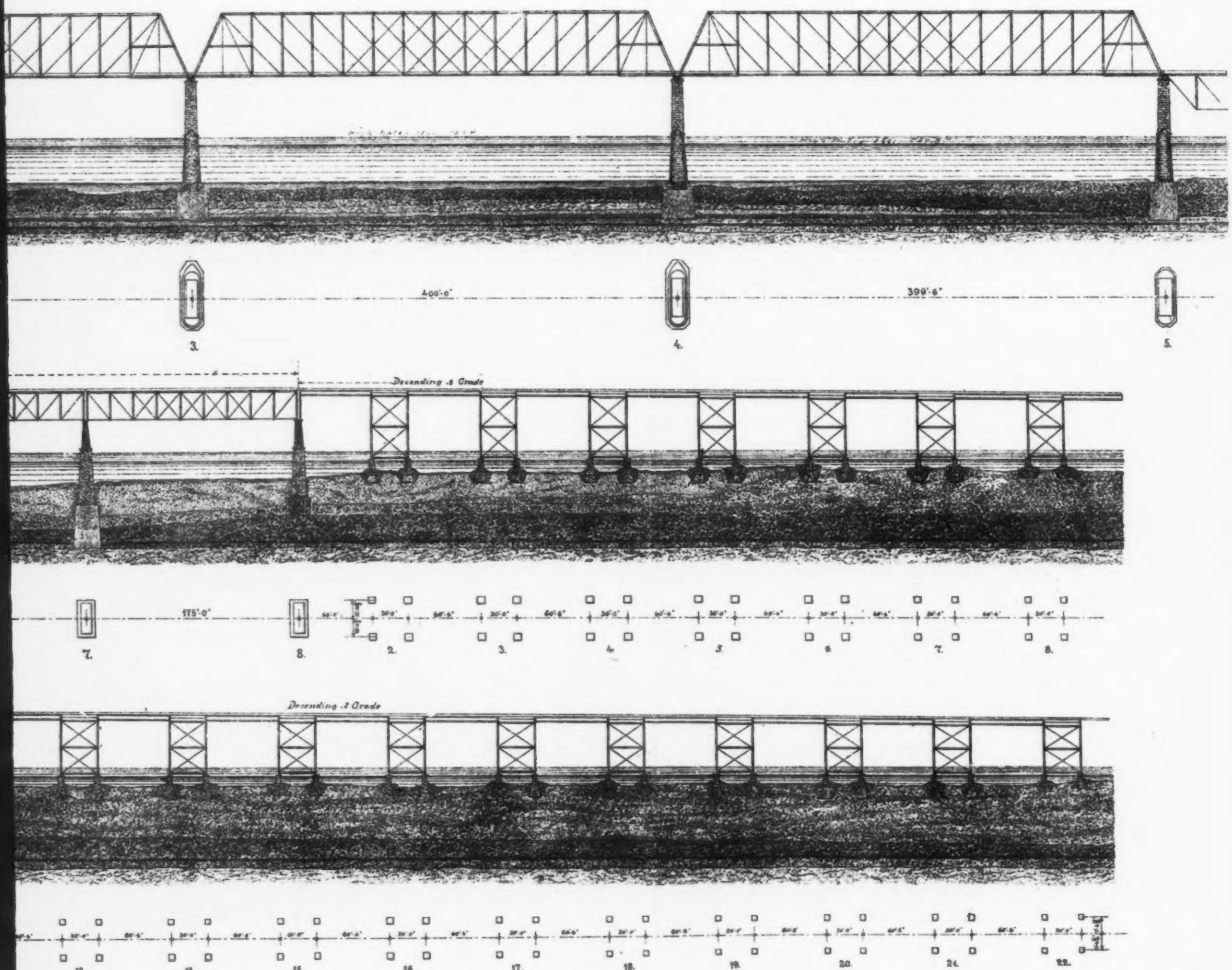
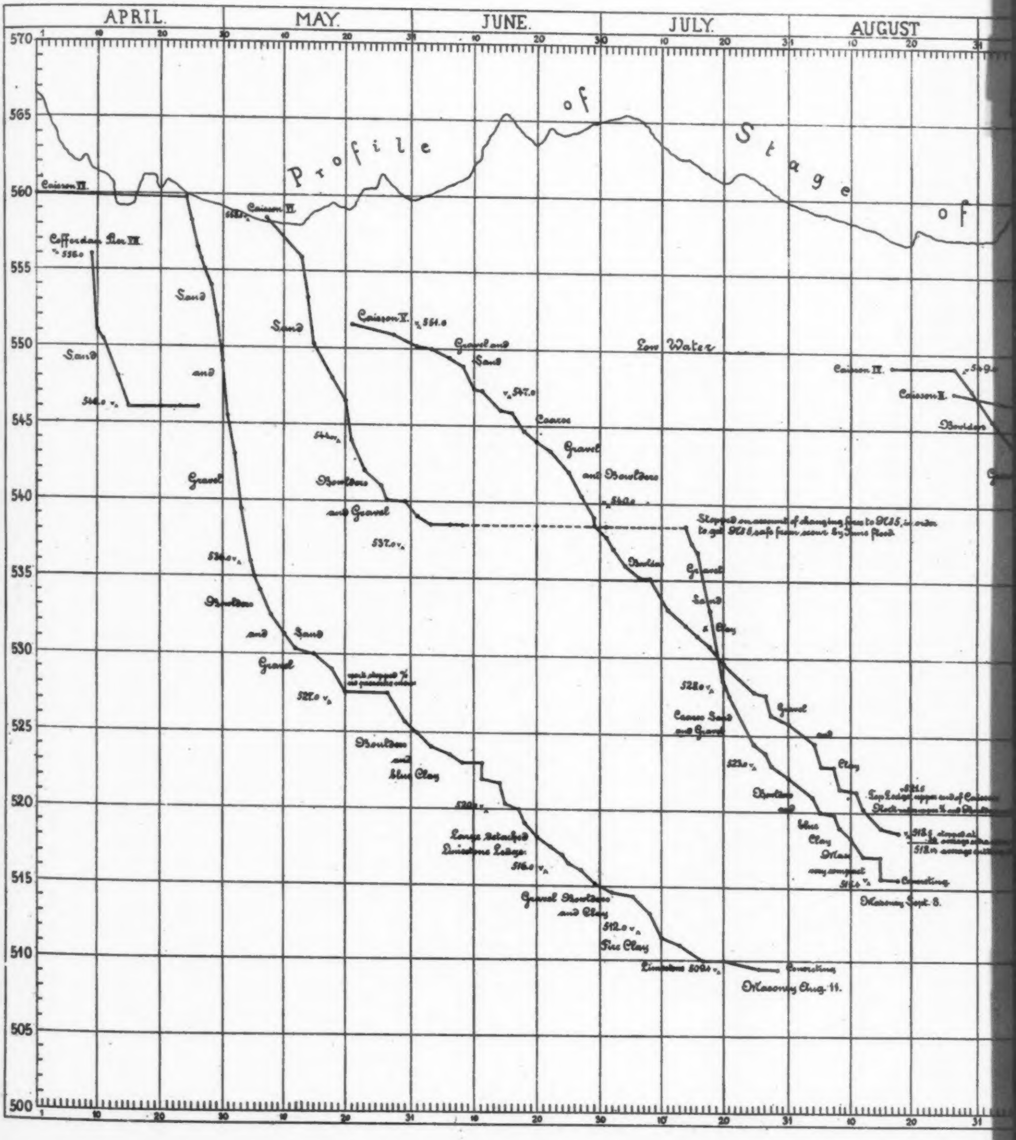


DIAGRAM SHOWING RATE OF PROGRESS IN SINKING CAISS



ATE OF PROGRESS IN SINKING CAISSONS

PLATE XXXIX
TRANS. AM. SOC. CIV. ENG'RS.
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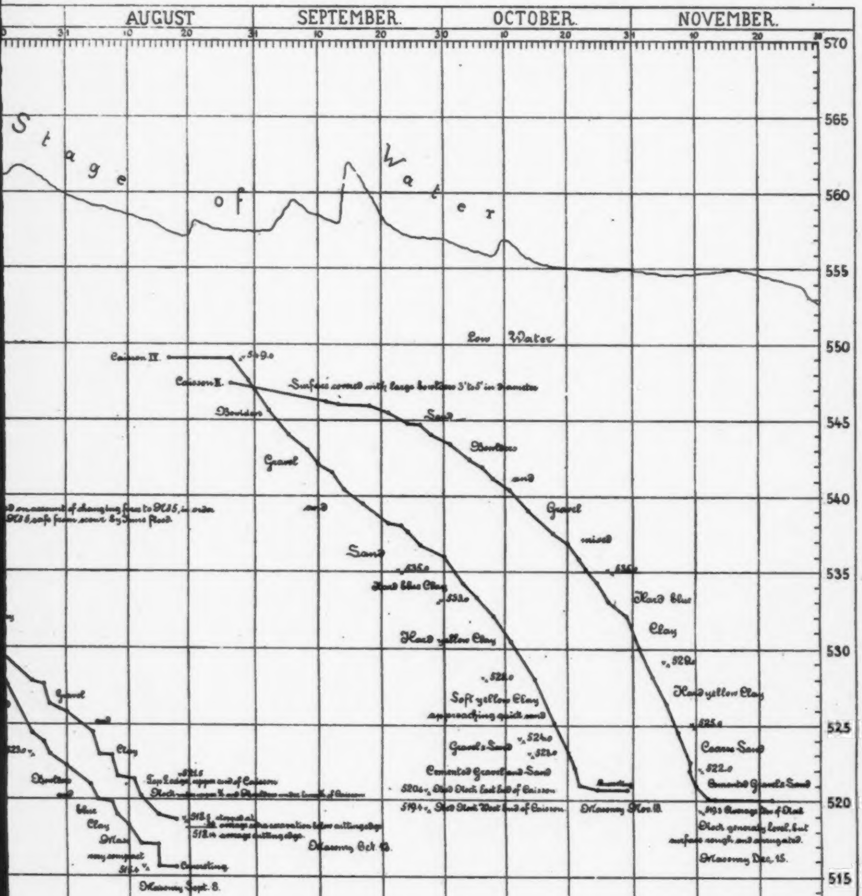
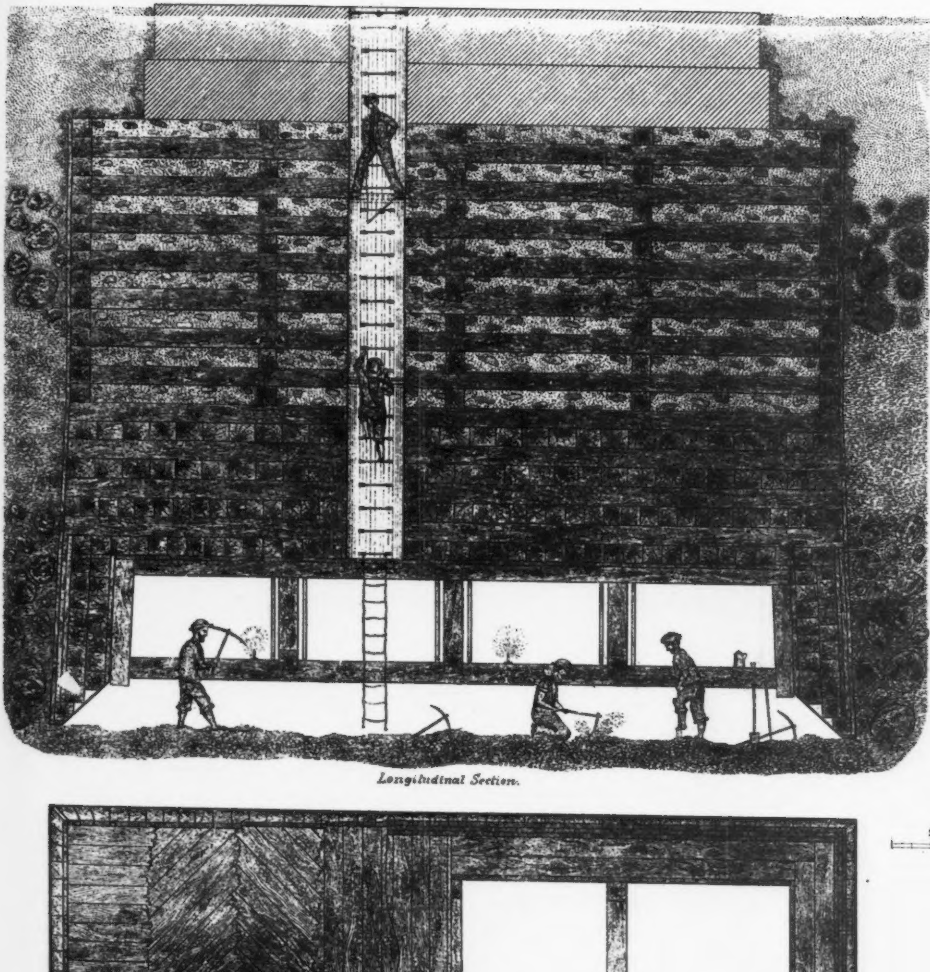
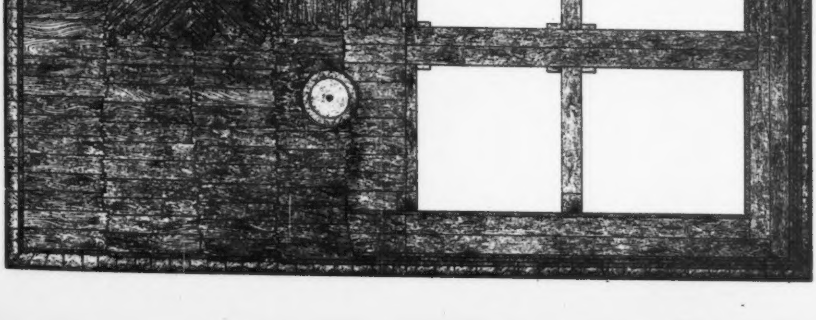
THE SIBLEY BRIDGE.





Longitudinal Section.



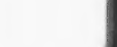


PLATE XL
TRANS. AM. SOC. CIV. ENG'RS.
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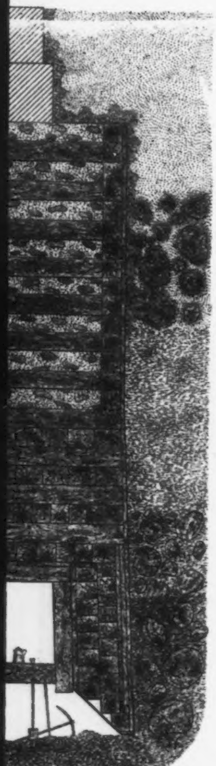
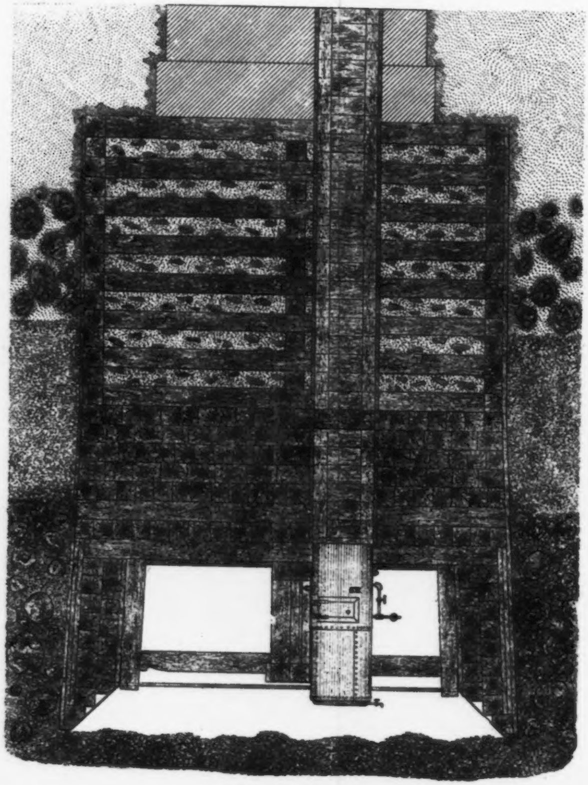
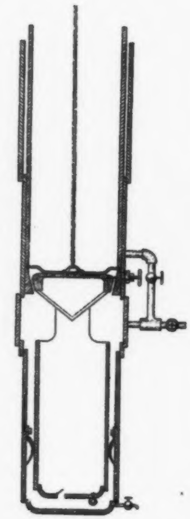
THE SIBLEY BRIDGE.

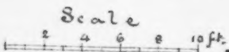
General Plan of Caisson.

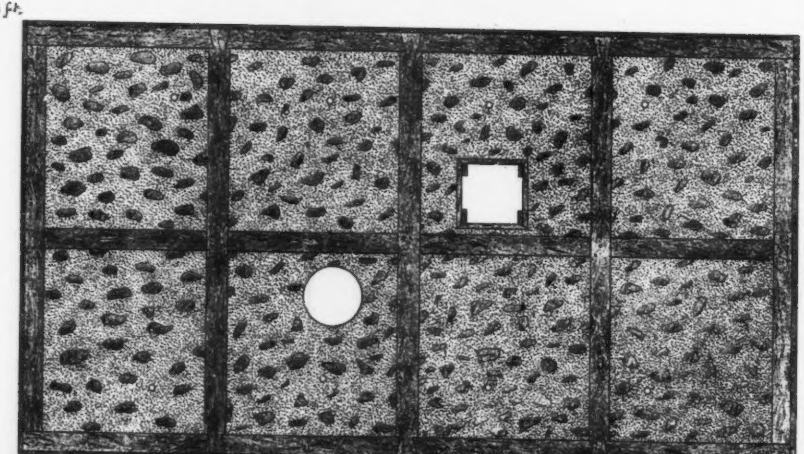




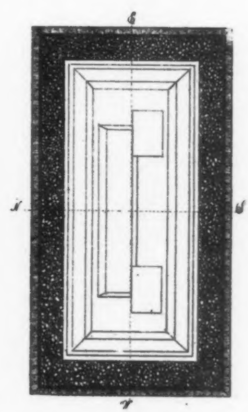
Cross Section.







ELEVATION
(South side)



PLAN

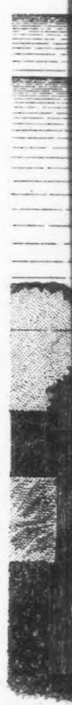


PLATE XLI
TRANS. AM. SOC. CIV. ENG'RS.
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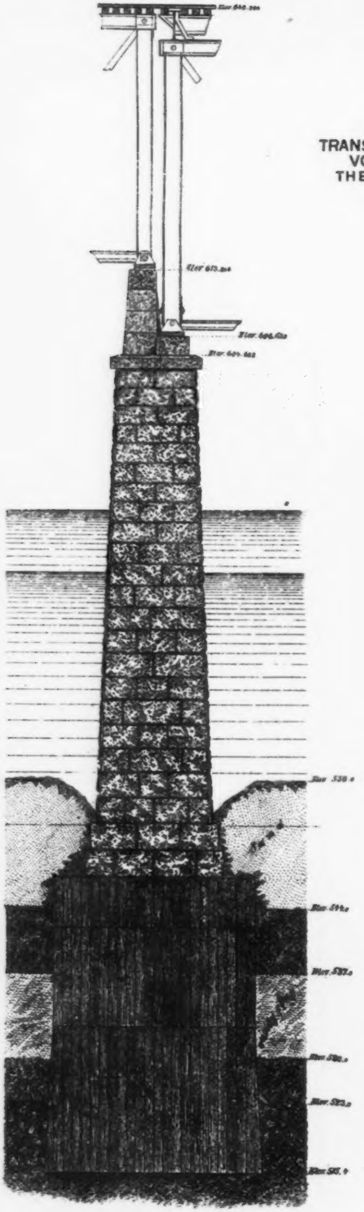
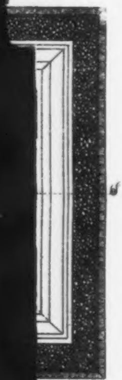
THE SIBLEY BRIDGE.

PIER Nº 6

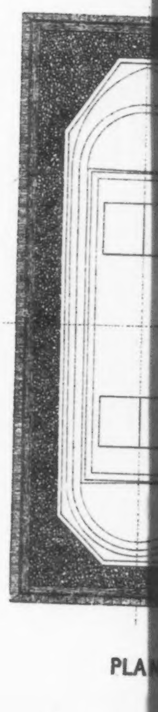
Scale:





ELEVATION
(West side)

ELEVATION
(South side)



PLAN

PLATE XLII
TRANS. AM. SOC. CIV. ENG'RS.
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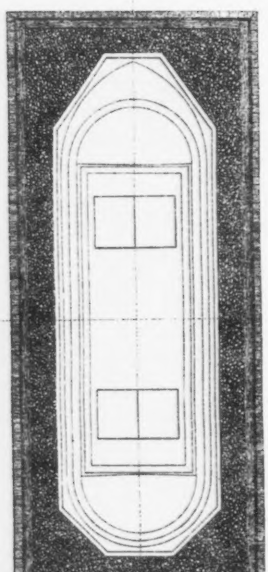
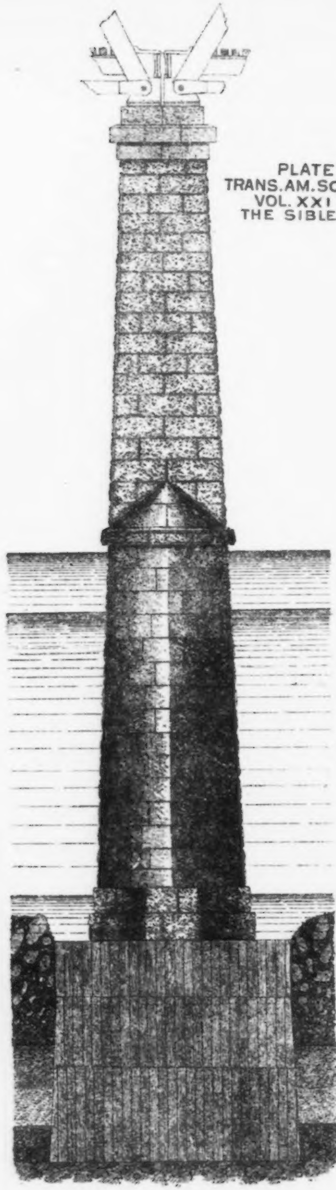
THE SIBLEY BRIDGE.

Pier No. 4

Scale: feet



PLAN



ELEVATION.
West-side.

PLATE XLIII.
TRANS. AM. SOC. CIV. ENG'RS.
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THE SIBLEY BRIDGE.

Scale

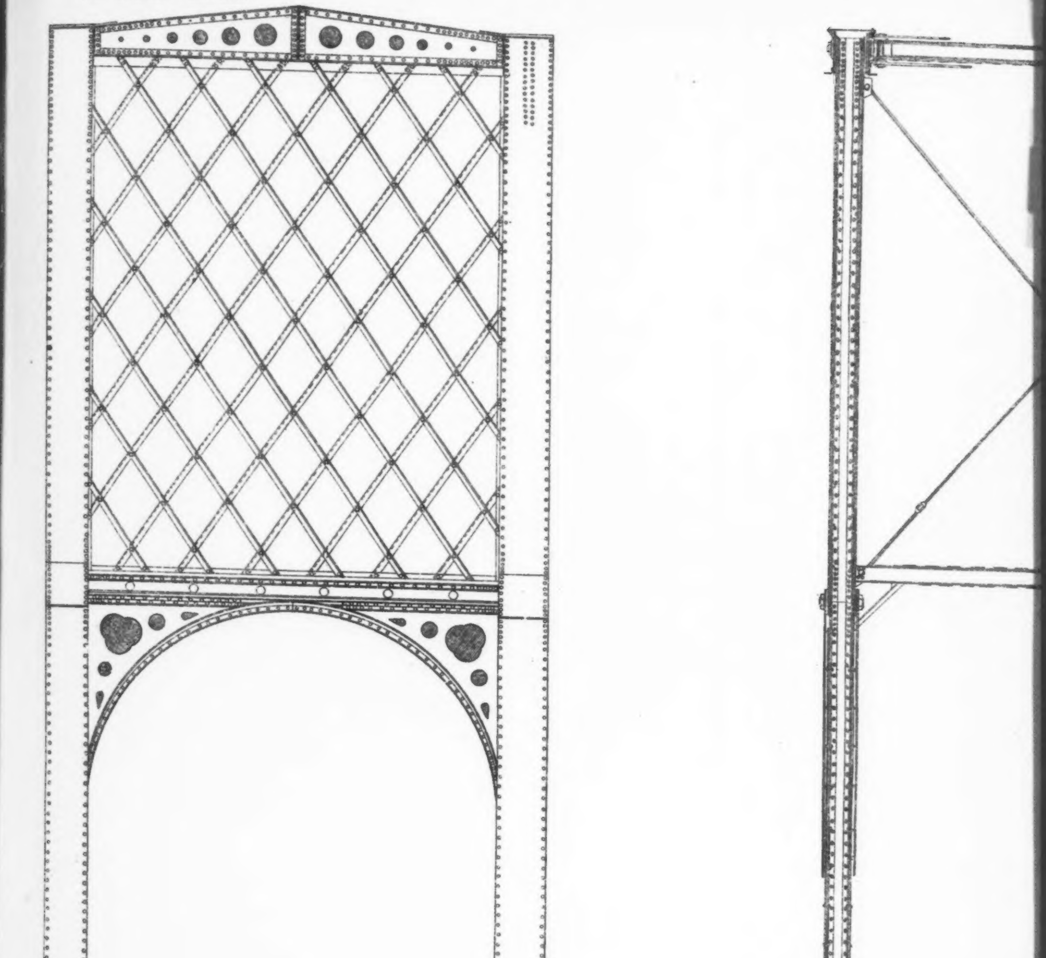
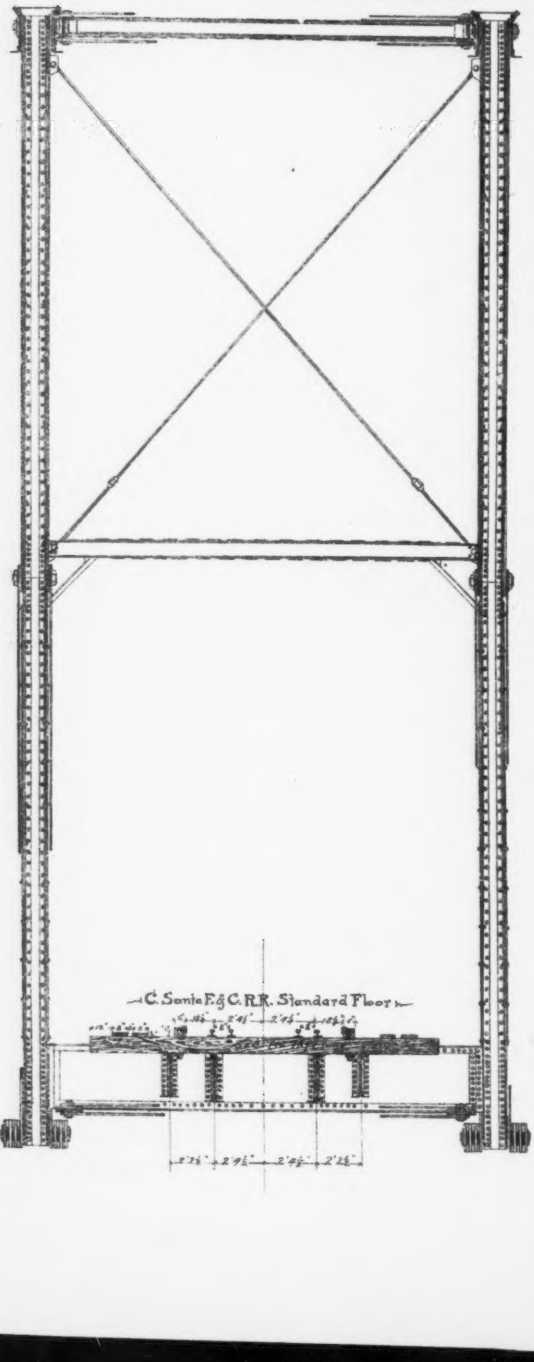


PLATE XLIV.
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XXI Nº 422.
THE SIBLEY BRIDGE.



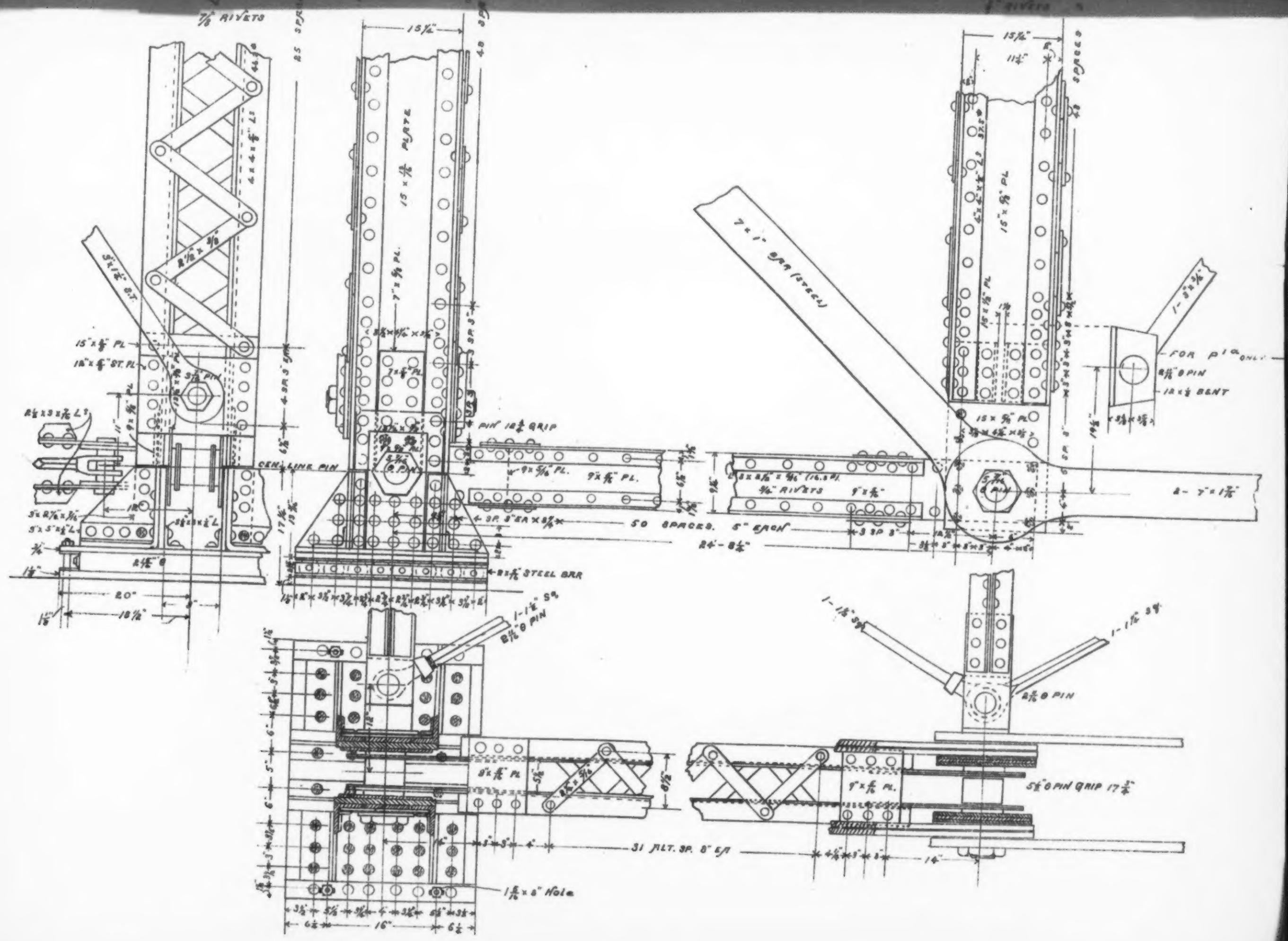
7/8 RIVETS
25 SPACES
48 SPACES
15 x 1/2 PLATE
7" x 5/8 PL.
CEN. LINE PIN
PIN 12 3/4 GRIP
9" x 5/16" PL.
50 SPACES. 5" EACH
24'-8 1/4"
STEEL BAR
7 x 1" BAR (STEEL)
15" x 5/8" PL
FOR P1a ONLY
12 x 1/2 BENT
2 - 7" x 1 7/16"
1 5/8 x 5" Hole
31 ALT. SP. 8" EA.
5 1/4" Ø PIN GRIP 17 3/4"
2 7/8" Ø PIN
1 - 1 1/4" SQ.
9" x 5/16" PL.
16"
14"

PLATE XLV
TRANS. AM. SOC. CIV. ENG'RS.
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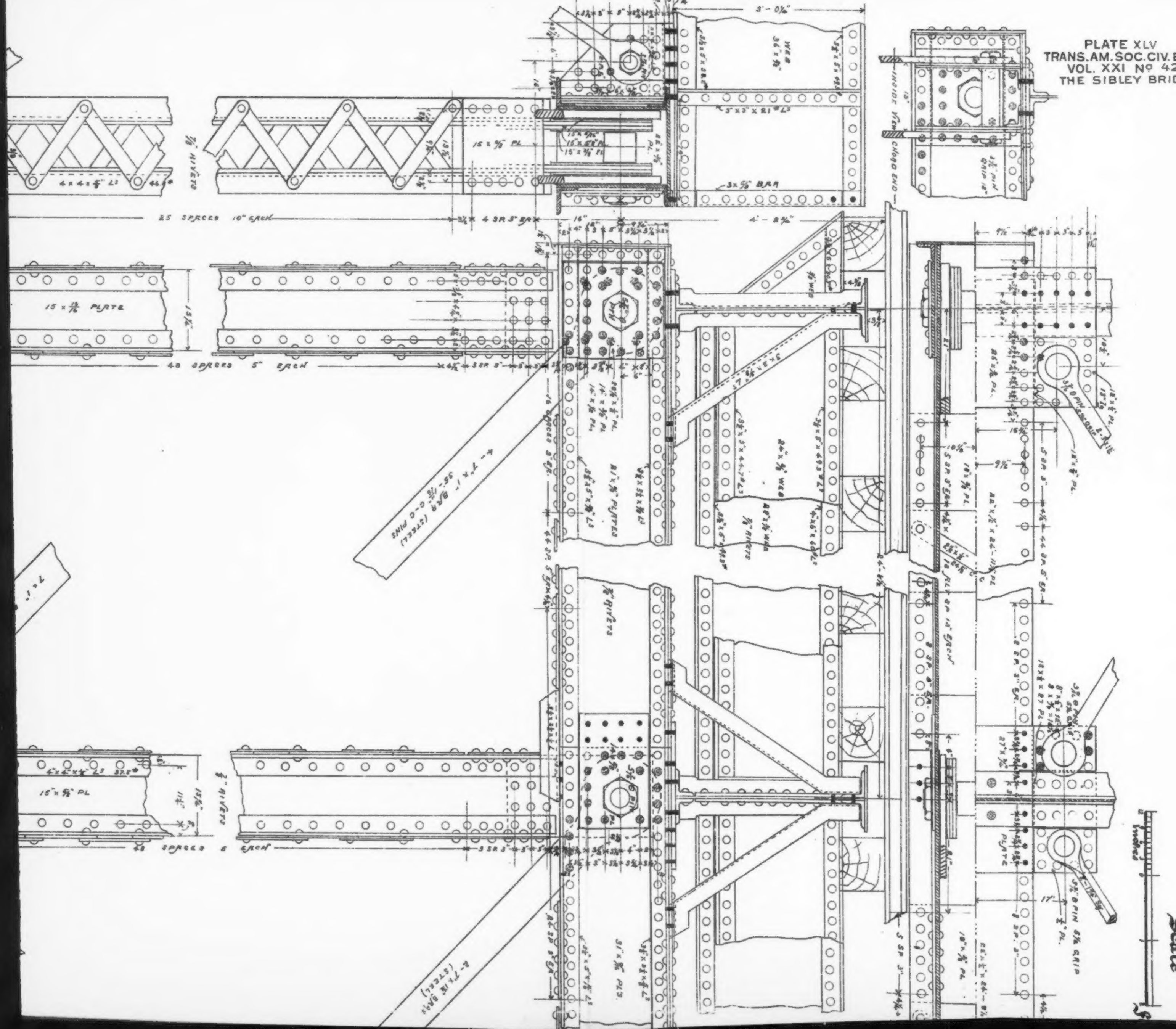
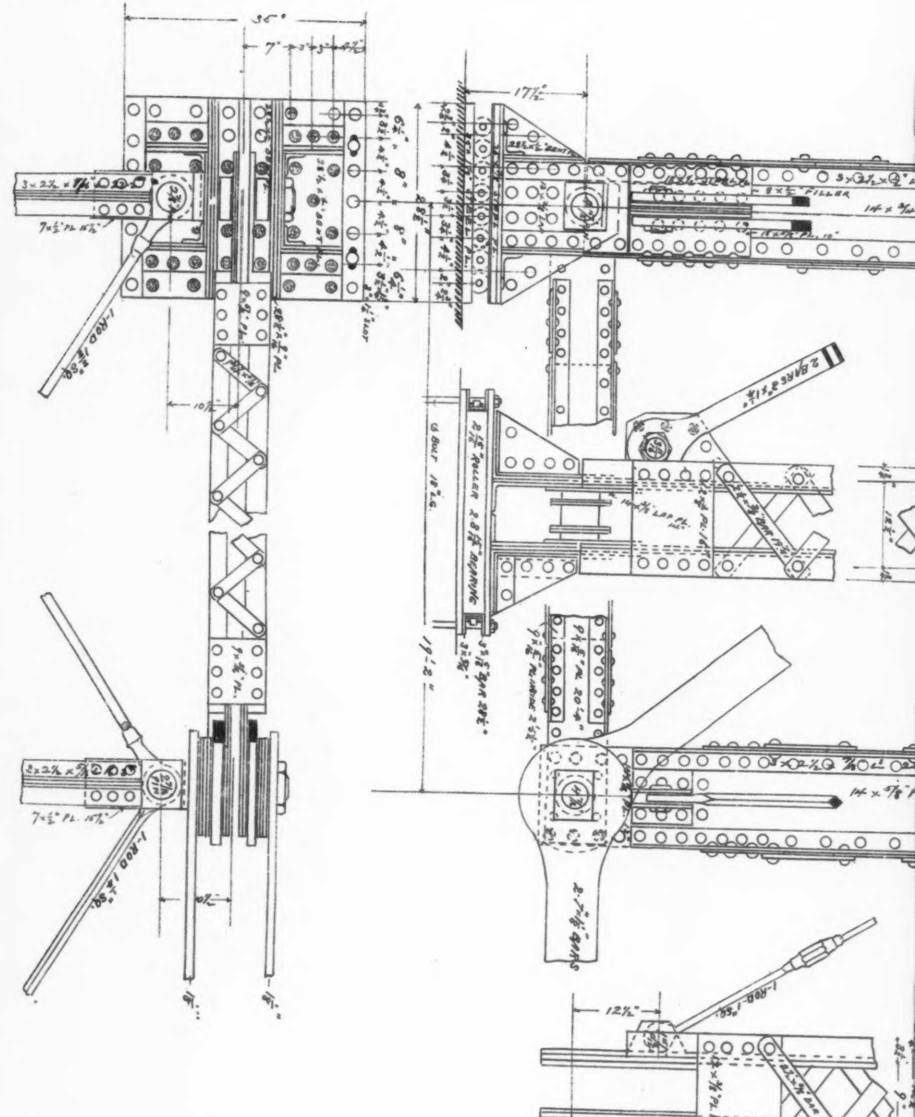
THE SIBLEY BRIDGE.





17½"
12½"
19'-2"
7×½" PL. 15½"
14×⅝" LAP PL.
FILLER

PLATE XLVI
TRANS. AM. SOC. CIV. ENGRS.
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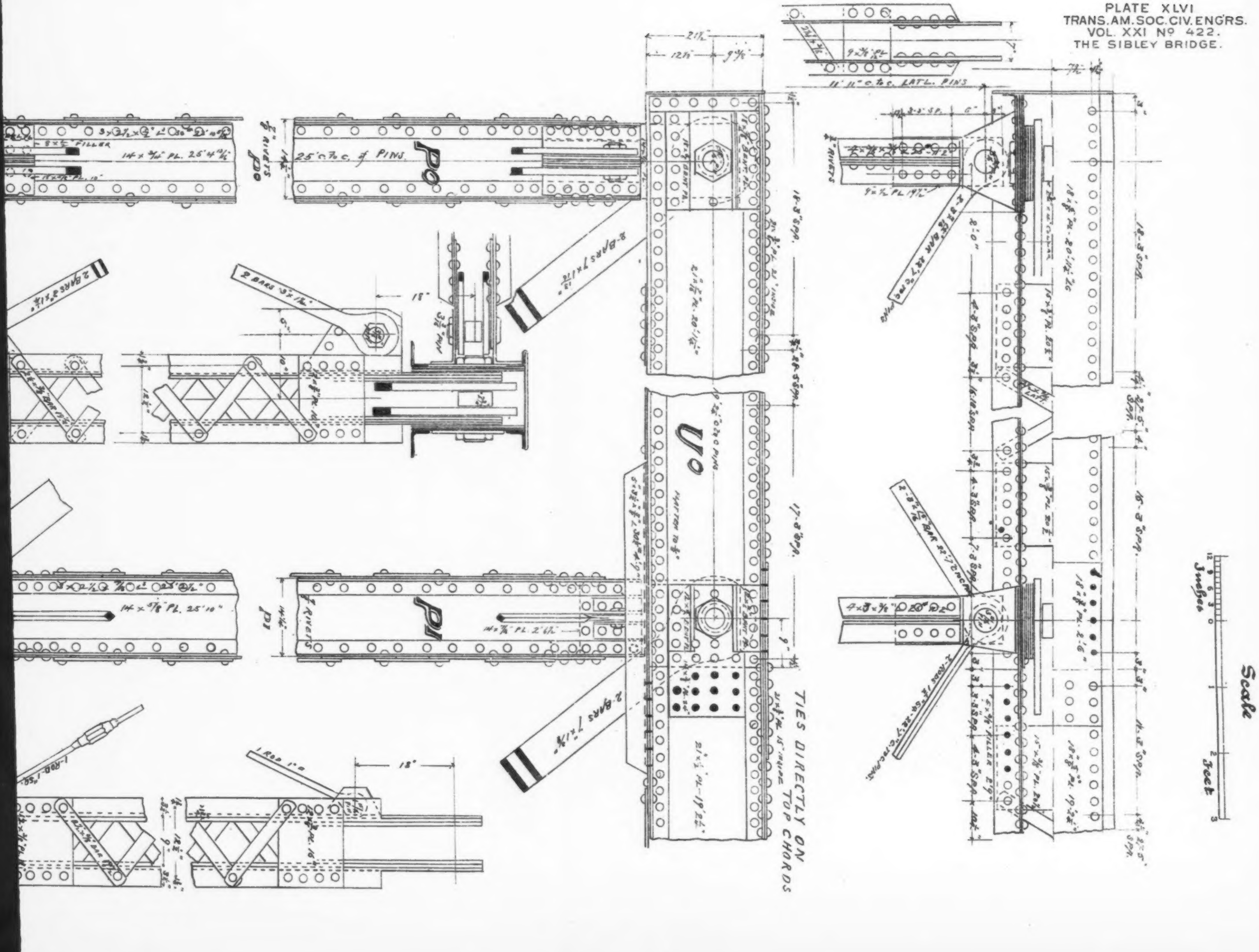
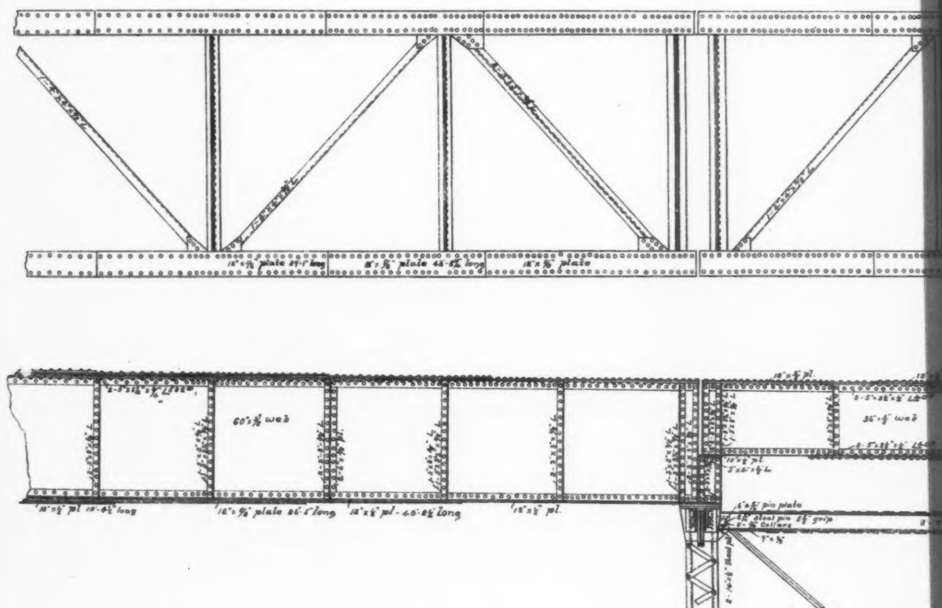
THE SIBLEY BRIDGE.




60"x 3/8" web
36"x 3/8" web
5"x 3/8" pin plate
12"x 3/8" pl.
12"x 9/16" plate 26'-5" long
12"x 1/2" pl.

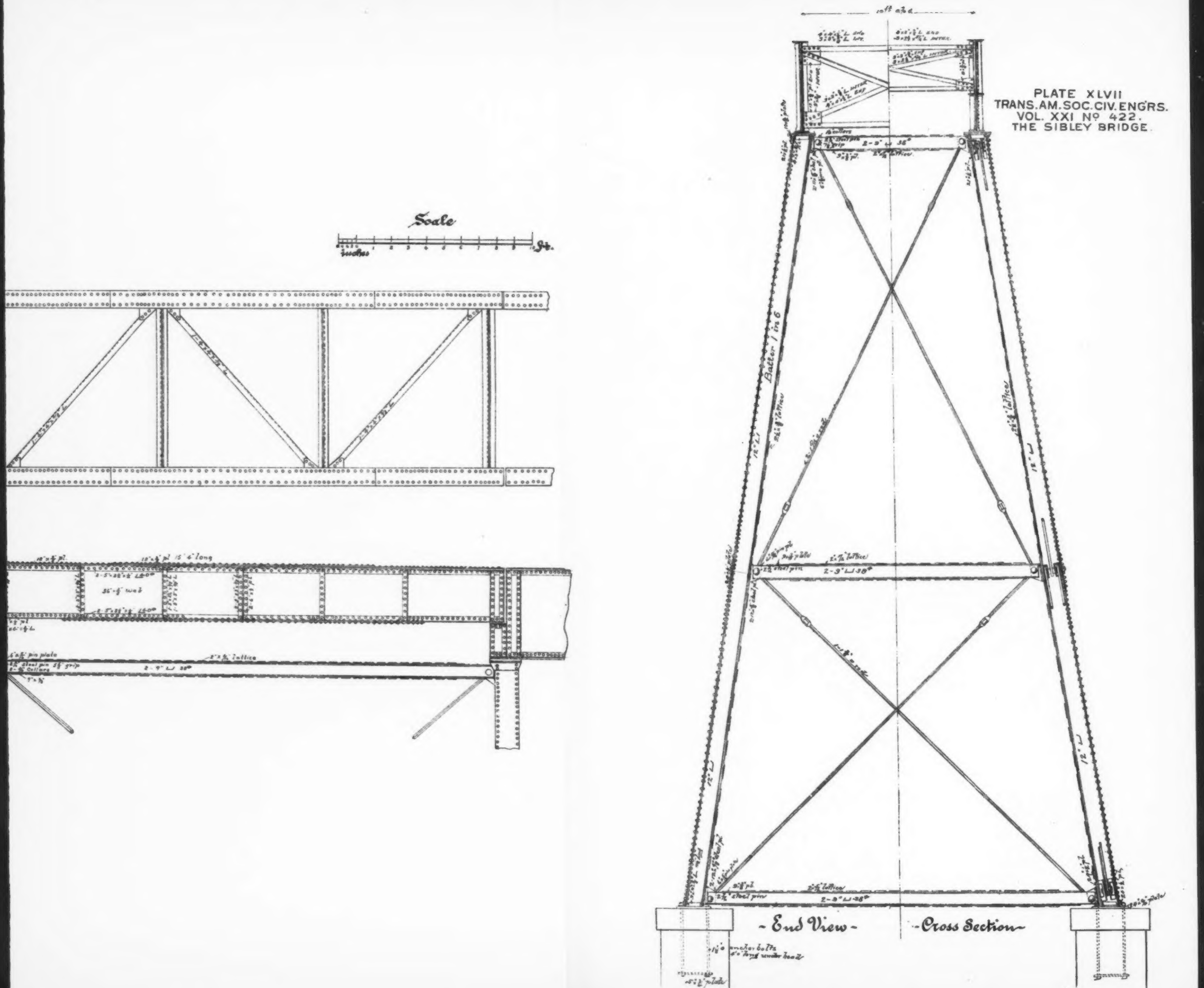


PLATE XLVII
TRANS. AM. SOC. CIV. ENG'RS.
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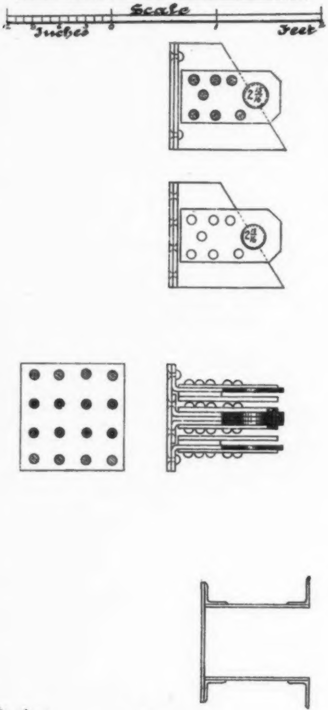
THE SIBLEY BRIDGE.
Scale
Batter 1 in 6
~ End View ~
~ Cross Section ~

Steel Compression Test Specimens

Approximate Fac-simile Top Chord Sections Reduced



Unit Strains

A

$$P = \frac{10000\left(1 + \frac{\text{min. stress in member}}{2\times\text{max. stress in member}}\right)}{1 + \frac{L^2}{30000\,R^2}} \qquad R^2 = 15.04$$

P = 11718 per sq. in.
Ult. Str. per □" developed by Test $= \frac{595400}{12.68} = 46956$

B

$$P = \frac{10000\left(1 + \frac{\text{min. stress in member}}{2\times\text{max. stress in member}}\right)}{1 + \frac{L^2}{40000\,R^2}} \qquad R^2 = 22.59$$

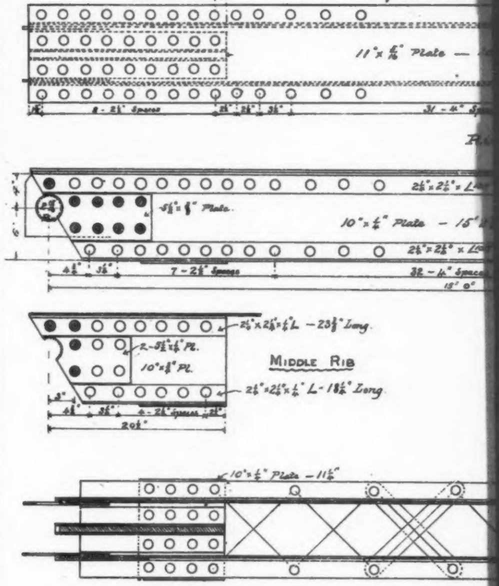
P = 11484 per sq. in.
Ult. Str. per □" developed by Test $= \frac{709800}{16.42} = 43238$

Specimen Tests on Material in both Posts.

	Ult. Str.	L.E.	% El. in 8"	% Red. of Area
Angles	76750	45860	22.8	47.1
Plates	81740	50370	22.5	33.62

N. W. Breithaupt
Engr. Insptr.

Specimen



Specimen

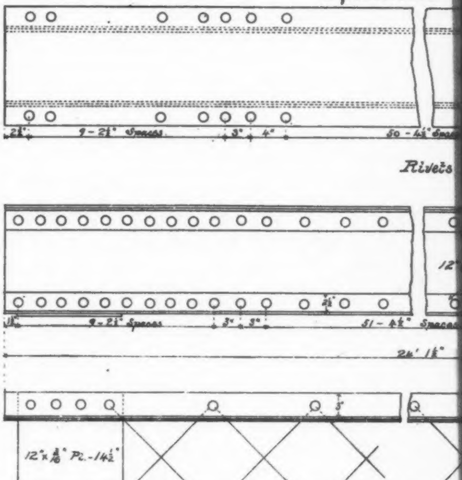


PLATE XLVIII
TRANS. AM. SOC. CIV. ENG'RS.
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